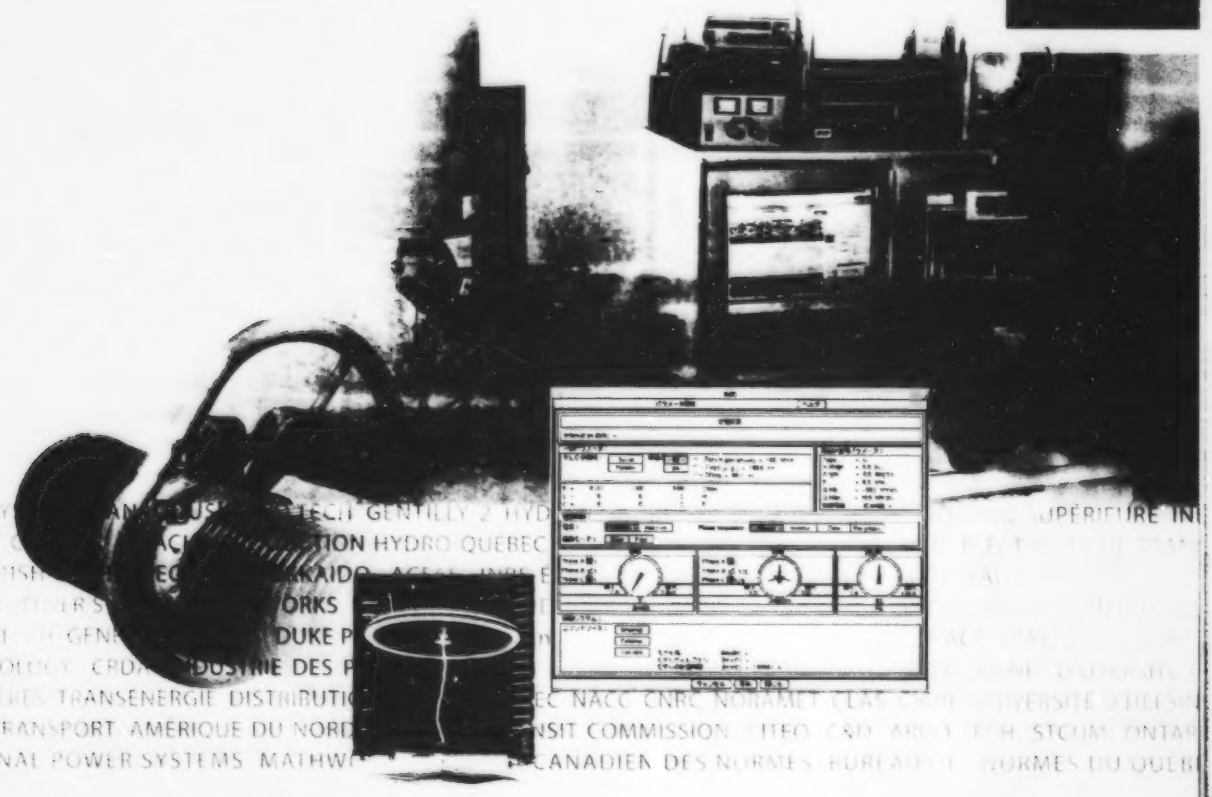
Research and Development

Highlights
1999



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30 years of research and development

Imagine the time: Quebec has just nationalized almost all of the province's electric utilities. It is the mid-1960s and Hydro-Québec, created 20 years ago, has become a "state-owned" utility, a symbol of Quebecers taking control of their economic destiny. One hydroelectric development follows another, the sky's the limit for our engineers. The first 735-kV high-voltage power lines have progressed from the drawing board to the work site and can be seen crisscrossing a burgeoning land.

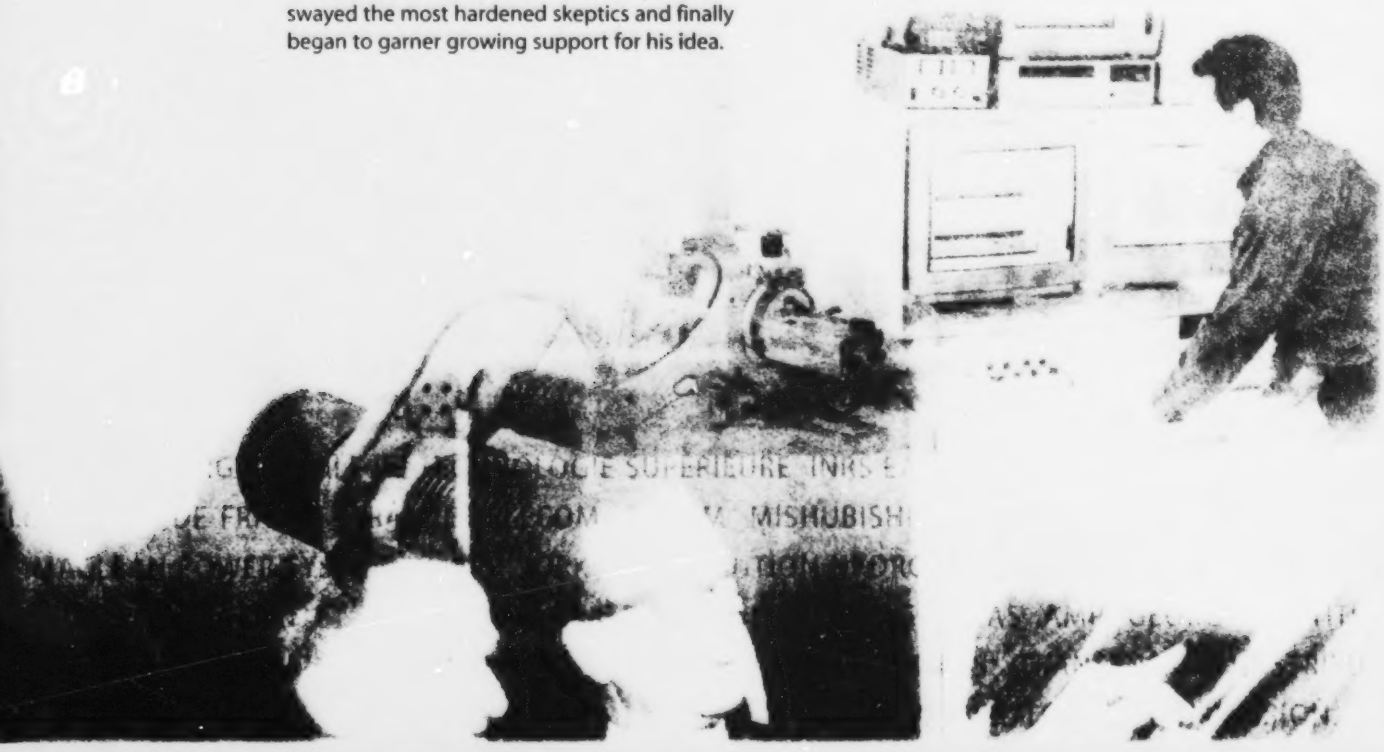
The "quiet revolution" which Quebec was undergoing in education, culture and the economy was also affecting the energy sector. Hydroelectric power would be part of Quebec's future; the province's songwriters wrote about it, its leaders proclaimed it, and industry was all for it.

At Université Laval, the chairman of the electrical engineering department, Lionel Boulet, came to the realization that there should also be a scientific component to the Quiet Revolution. This was a time when Quebec depended on outside laboratories to solve a great many of its technological problems. But Mr. Boulet thought that this should be handled by Hydro-Québec's own research centre. All that remained was to convince Hydro-Québec management. To each member of management in turn, he demonstrated, over and over again, how Hydro-Québec would benefit from taking charge of its own research and development. He met all their objections, swayed the most hardened skeptics and finally began to garner growing support for his idea.

In 1964 the utility asked him to look into setting up a research centre in energy in Quebec. One year later, Mr. Boulet submitted his report. In it he reviewed energy research worldwide and used it to support the idea of setting up a research centre in electricity. In the fall of the same year, convinced of the need to have its own research centre, Hydro-Québec set up an advisory committee made up of representatives of the government of Quebec, universities, industrial research and of its own main technical and financial departments. Two years later, on February 6, 1967, during electricity week, Quebec's premier, Daniel Johnson, unveiled the model of the future Institut de recherche d'Hydro-Québec.

Experts from around the world joined a core group of Quebec research scientists. The dream was becoming a reality. On September 29, 1970, the centre, which was to become one of Quebec's finest assets in scientific research, was inaugurated.

Over the 30 years that followed, IREQ's experts in science and technology have contributed, through their research and testing, to Hydro-Québec's electrical engineering expertise, which is now the pride of Quebecers and the envy of many producers and distributors of electricity around the world.



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New impetus in innovation

Roger Lanoue

Denis Pelletier

There is no doubt that the R&D work described in this report is a major challenge for Hydro-Québec. Innovation drives our development, and our growth is fulled by R&D spinoffs and the application of our research findings.

However, it has become clear that the utility has not been able to fully capitalize on its substantial R&D investments over the years, to the point that we now question our ability to transform our research results into spinoffs both within the utility and without.

It is not the quality of our research that is at issue, or the competence of our scientific personnel. The problem lies in the failure to capitalize on R&D successes and the fact that there is no value-adding process to bridge the gap between ideas and their application. Furthermore, our R&D portfolio consisted of highly disjointed projects.

This is why we are concentrating on bringing together the conditions most conducive to innovation by launching the "ESPRIT" project.

We knew that we had to focus our efforts on R&D projects with a definite impact on the utility's basic areas of activity. However, senior management would then play an even greater role in defining and in following up on research projects. Each of the utility's business units also needed to become more directly involved in managing its research. Finally, it was necessary to give a fresh impetus to the technological innovation process by stressing teamwork revolving around the major avenues of research and prioritizing value-adding activities.

The first step in this process involved defining the major R&D issues in the utility's strategic plan. The second step was to create platform teams for each of Hydro-Québec's strategic sectors, i.e. the generation, transmission, distribution and application of electricity.

The teams, which included an R&D representative, a representative from the applicable business unit, and another representative from the technology value-adding directorate, were mandated to oversee the newly set-up process of integrated innovation management, which would bridge the gap between researchers' ideas and their application. The purpose of the platform teams will thus be to manage the utility's investments in innovation so as to maximize their economic impact. They will be required to define, based on the major R&D directions previously determined by senior management, innovation avenues which will allow Hydro-Québec to improve the reliability of its electrical supply, ensure greater service continuity for its customers, boost energy efficiency, and optimize the use of its installations. Each of these avenues will be assessed based on its economic and strategic impacts, its technological content, the scope of the projects likely to meet the target objectives of the various avenues, and the balance to be maintained over the short, medium and long term.

This more stringent management of the project portfolio, teams, budgets and timetables should favour quick and systematic assessment of R&D ideas as well as an estimate of the potential gains, costs, lead times and technical feasibility. The focus will be on value-adding and the participation of venture-capital experts in order to step up the validation and assessment of the outside potential of R&D ideas. Lastly, the implementation or commercialization of new technologies will be facilitated, and unpromising projects will be quickly terminated.

In the past, too many great ideas from our researchers came to naught, too many R&D investments failed to create the expected spinoffs, and too many commercial prospects were financial disappointments. As a result, research and development itself was in jeopardy. By bridging the gap between idea and application, by involving all the players – from senior management to the business units, to R&D, to added-value and venture-capital specialists – in an integrated innovation process, it is hoped that innovation will gain new impetus through the "ESPRIT" project.

Denis Pelletier
General Manager – Research and Development – IREQ

Roger Lanoue
Vice President – Research and Strategic Planning

The research and development conducted at IREQ supports the operation of our facilities from three perspectives: efficiency, safety and cost-effectiveness. This has been proven through recent work such as the development of techniques and products which ensure that the cracks in the Daniel-Johnson dam are properly filled, the development of analysis models and digital simulation tools for fluid flow in hydraulic turbines, and the design of robot systems for inspecting Gentilly-2 nuclear generating station.

R&D thus plays a crucial role for us. We must take full advantage of the benefits of R&D, ensure that it directly enhances the performance of our installations, and that it also has economic spin-offs. This means that a structured and consistent approach must be used. This is why our experts, research teams, specialists in value-adding and venture capital, and even our outside partners are working closely in keeping with the target areas and our needs.

The utility has set up a new innovation management process which will allow us to move ahead. I see it as a way to ensure that R&D will make an even greater contribution to our strategic objectives and cost-effectiveness. Capitalizing on technological innovation will undoubtedly lead to increased reliability in meeting demand at an optimal cost.

Lastly, our objectives for the next few years involve major challenges, including the design of new facilities, the safety and continuity in service of our installations, and the performance and energy capability of our generating facilities. To help us meet these challenges, we are counting on everyone involved in R&D and innovation, both within the utility and without.

Ghislain Ouellet
Vice President – Operation of Generating Facilities

Filling of cracks in the Daniel-Johnson dam

In conjunction with drilling and dam-repair specialists from the Manicouagan Region, we successfully carried out a project to fill the cracks running across the Daniel-Johnson dam, a massive multiple-arch structure. We sealed up the two cracks in arch 5-6, one of which was 0.1 to 4 mm wide and extended over 260 m² of the dam's surface.

About 30 injection campaigns had already been carried out from 1970 to 1980. However, the techniques and products available at the time could not properly fill the cracks. Three of these campaigns even caused the cracks to spread instead of sealing them, with some of the cracks crossing the dam structure. In 1985, therefore, Hydro-Québec issued a moratorium until an adequate, efficient and safe method could be developed. The Manicouagan Region then called on IREQ's specialists. The objective was to develop techniques, equipment and products to fill the micro-cracks in concrete dams, especially the cracks running across the Daniel-Johnson dam, without in any way compromising structural integrity.

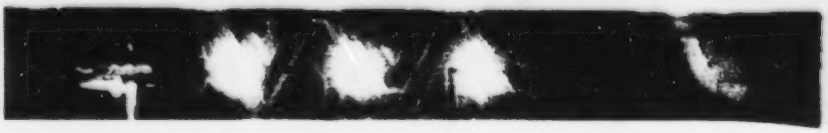
Efficient control and monitoring systems

To this end, we recreated the dams' actual operating conditions in the laboratory. Using a one-of-a-kind test bench which uses large concrete slabs measuring 2.62 x 142 x 0.6 m, we succeeded in recreating a range of parameters, such as crack opening and incline, temperature, moisture, and water pressure upstream of the dam, and in simulating fracturing and injection under controlled conditions. We chose different products and defined the injection parameters, especially regarding each product's rate of pressure and flow, and validated the techniques that were retained. Once the product performance tests were completed, we selected microfine cements containing superplasticizers, mainly because of their permeability and rheological and mechanical properties. Injection is a very delicate procedure – it is essential to stay within a pressure threshold to avoid enlarging the crack – so we developed control and monitoring systems to continuously monitor the procedure.

Based on an agreement made in 1998 with the Facilities Group, our findings and expertise were used in crack injection campaigns at the Lacroix, Carillon, Rapides-des-Quinze and La Gabelle dams, among others. Given the results obtained, a committee of international experts recommended lifting the moratorium on injections at the Daniel-Johnson dam.

In January 1999, in conjunction with the Manicouagan Region, we thus began filling the cracks running across arch 5-6 of the dam. The procedure, which was carried out around the clock for six days, required 63 injection sequences. Using our control system, we continuously monitored the work and were thus able to regulate the injection pressure within the prescribed limits. In fact, the system detected abnormal pressure levels on over 50 occasions, thus demonstrating its efficiency and usefulness for safe injections.

After the campaign, several inspections confirmed the quality of the work. In fact, the filling of the long cracks completely eliminated the water underpressure in the cracks as well as water infiltration, amounting to 14 l/s, and improved the structural integrity of the dam.



New approach for forecasting cracks in turbine runners

Until recently, cracks in turbine runners were considered to be isolated cases which did not warrant a more in-depth analysis of their causes. However, no explanation could be found for some of the phenomena. For instance, some of the cracks analyzed during the 1980s, to which seemingly definitive solutions had been applied, have reappeared without any "conventional" explanation. Moreover, cracking has been observed which is not consistent with other in-service turbines and, at one generating station in particular, cracking occurred in unexpected places, such as in the crown rather than at the weld fillet where the concentration of stresses is highest. Moreover, no explanation has been found for cracking around the band; this area is subject to few stresses from normal operating loads and should not crack.

Improving knowledge of fatigue mechanisms

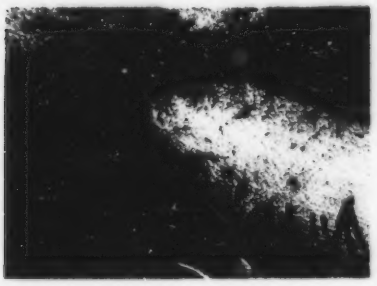
Damaged turbines can be divided into three categories. The first consists of very old ones which are nearing the end of their useful life. In this case, adequate repairs and change in the area where stresses are concentrated could prolong their life, postponing the need for major investments or upgrading work. The second category comprises turbines built in the 1970s and 1980s. At that time, the concentration of stresses in turbine runners was improperly assessed due to the calculation tools used back then and the limited processing capabilities of computers. The last category, turbines built in the 1990s, presents a different problem. Though the stress concentrations were properly calculated, cracking appears in totally unexpected places.

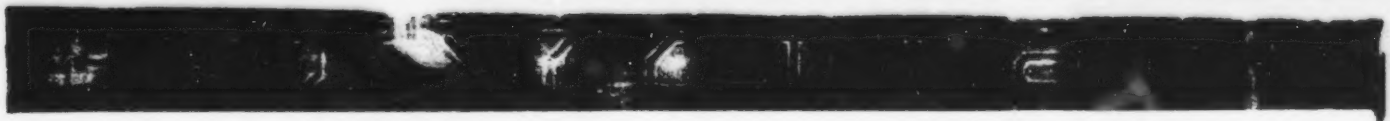
Numerical calculation tools are accurate enough to predict operating-related stresses. However, the analyzed turbines showed that cracking does not always occur where calculated and may even occur in places where forecasts indicate there should be no cracking. Furthermore, cracks continue to appear in turbine runners that have been repaired and retrofitted.

These observations show that the approach used to analyze the turbines is incapable of explaining this behaviour, which is why we suggested studying the failure mechanisms which lead to cracking. This would help us predict the risk of cracking and increase the service life of the installations.

We have devised an approach which involves calculating the risk of cracking by taking into account the potential condition of the runners when they are put into service along with the operating conditions they are subjected to. The condition of the runners when they are put in service corresponds to the level of residual stress, which depends on the assembly techniques and the amount of solder used to manufacture the runners. The operating conditions analyzed so far determine the number of fatigue cycles to which the turbine is subjected. It is therefore important to keep in mind the effects on the duration of each type of operation: start-stop, load shedding, normal operating conditions, etc.

Our approach aims at isolating each element and demonstrating its relative importance in relation to the overall fatigue calculation assessment.





New diagnostic methods for generator units

Last year's research revolved around partial discharges and advanced dielectric methods, as well as the development of repair methods for extending the lifespan of generator units.

Our team produced an upgraded version of the LISA software used by generating station personnel to analyze partial-discharge spectra. In addition, phase resolution analysis has made considerable progress and should soon be part of the diagnostic toolbox.

In conjunction with Gentilly nuclear generating station experts, we developed an approach for monitoring partial discharges in the plant's 675-MW alternating-current turbogenerator. The data are transmitted by modem to one of our computers to ensure continuous monitoring and timely response to emergencies.

Procedures for prolonging generator service life

Moreover, we improved the BARTACT system, which is used to check the lateral wedging of generator stator windings and their degradation by vibration and by slot discharge. The data have now been transferred to an Intranet data base.

In terms of materials, various procedures for repairing damaged stator winding end-arms are currently being subjected to accelerated-aging tests, and we should soon be able to determine the best ones. Promising work is also under way to optimize a method whereby conducting paint is injected to restore the conductivity in the stator winding semi-conducting wall.

Meanwhile, development of the ITERG and TESTERG diagnostic methods continues. The ITERG method is now fully automated and the results are obtained through a highly sophisticated analysis software program which shows the state of the stator or rotor windings and suggests actions to be taken, such as cleaning or applying stress-grading paint on the end arms. The TESTERG method is still in the experimental stage and tests involve monitoring the accelerated aging of the model's windings at the high-power laboratory's medium-voltage station. We are working on making this test automated. The instrumentation includes a programmable AC source, and the whole assembly is mounted on a trailer. Once it is fully developed, the TESTERG method will be able to detect certain electrical faults on rotary machines.

Lastly, we completed our project to assess service gains by inverting the neutral point, and the instrumentation has been delivered to the client. The deliverables include a decision-making software whereby the user selects whether or not to invert the neutral on the generator phases in order to prolong the generator's useful life. We also proposed a new project (known as "ZERG") to the client. It is aimed at exploring the lifespan forecasting capabilities of a method based on impedance dispersion.

New universal measuring station

The development of a universal measuring station for the dam safety department in Hydro-Québec's Generation Group was completed at the end of 1999. Designed to energize and read most of the sensors installed in the dams, the station improves the quality of measurements and facilitates the work of dam inspectors. It reads most types of vibrating-string sensors, 4-20-mA sensors, RTDs, thermistors and potentiometers. Like a multimeter, it can also measure voltage, current and resistance.

Our new measuring station has many advantages. For example, only one station is needed to scan most of the sensors installed in the dams and the station has a highly user-friendly man-machine interface, which includes an active matrix display with a 320x240-pixel resolution and a touch screen. Designed to be operated in harsh environments, the station validates data *in situ* and transmits them to a PC. The resulting data can then be transmitted to a conventional PC data base. Lastly, the user only has one device to handle, calibrate and repair.

For most dam, bridge and tunnel sensors

The station is designed for dams, but it can be easily adapted to most sensors used in civil-engineering structures installed in bridges and tunnels.

After validation, tests were carried out at the La Grande and Manicouagan complexes in 1999, we were able to fine-tune the device's measuring algorithms. In 2000, we will be working on linking the universal measuring station with the dam safety department's provincial data base. Two pre-production units have been delivered to the client and we expect to manufacture another 20 stations in early 2000 to meet Hydro-Québec's needs. Talks are also under way with a view to marketing the device in the future.

The HSAMI hydrological model

To optimize hydroelectric generation and minimize the risks involved in managing water resources (flooding, low flow, etc.), Hydro-Québec has been forecasting water inflows to its reservoirs and generating stations using a conceptual hydrological model known as "HSAMI." The model takes into account soil moisture conditions, snow accumulation, short-term weather forecasts and climatology.

The computer system on which the model is installed is obsolete so it had to be transferred to a more recent platform. This process had already been started by Hydrosoft Énergie, a subsidiary which markets an integrated generation management system, using an inflow forecasting tool based on the Hydro-Québec model.

We decided to adapt this tool. The new forecasting system, which is now being tested, produces daily forecasts for all of the 92 drainage basins managed by Hydro-Québec. In addition, the algorithms were validated and documented, and the system's weaknesses identified.

We are now working on improving the system in conjunction with the *École de technologie supérieure* (ETS) and the *Institut national de recherche scientifique* (INRS-Eau). We intend to replace the algorithms used to estimate the condition of the basin and the model's parameters and to integrate the forecasting system into a geographic information system (GIS). For basins where more accurate forecasting is needed, we plan to install the HYDROTEL distributed hydrological model, which is more precise but much more complex. HYDROTEL associates a sub-basin with each river section and models the hydrologic budget and flow for each sub-basin. HSAMI, however, subdivides the whole basin into only three sub-basins for calculation purposes. We also intend to integrate Environment Canada's long-term weather forecasts.

Improving the accuracy of inflow forecasts

We hope to replace the current system with the new version by the end of the year. The new system should improve inflow forecasting accuracy over the short, medium and long term. Moreover, the system is easier to use and to integrate into other generation planning tools.

Planning which reflects variations in natural reservoir inflows

Considerable progress has been made in the area of long-term planning of primarily hydroelectric generation, which must reflect variations in natural reservoir inflows. In fact, after adopting a new approach, i.e. stochastic dynamic programming (DP) combined with parametric linear programming (PLP), we developed a prototype code for the Stochastic Dual Dynamic Programming (SDDP) method, which our department has been promoting ever since it was developed by a Brazilian researcher a few years ago. Using sophisticated optimization techniques, we compared the two approaches, which work directly on large-scale generating systems without requiring the use of a heuristic and approximate reservoir aggregation-disaggregation mechanism. We retained the SDDP approach, which offers greater optimality and a simpler code.

The prototype code was then incorporated into the Io integrated system used by the generation planning department. The Io system is used to define the characteristics of future developments so they can be optimally integrated into the existing generating system. It takes into account future electricity demand as well as plant and market characteristics (e.g. head, transmission-related constraints, contracts with neighbouring systems, and purchases from independent power producers). It also helps planners define the role of future peak-load generating facilities by calculating generation over weekly and seasonal intervals, as well as optimize the installations based on a number of inflow and demand scenarios. The Io system comes with a graphical user interface which runs under Windows 95 and displays the hydrographic system, especially valleys, and the transmission system.

In 2000, we will refine the SDDP prototype code, after which it will be used by the planning and generation strategies department for multiyear generation planning over a timeframe of three to five years. We will thus be able to represent the generating system more accurately by including such aspects as a simplified transmission system. This will lead to optimized results and a better framework for annual planning, which is the next step in the overall layered process used in generation planning.

MÉTAR bracelet: tests at Gentilly-2 and marketing agreement

In December 1999, Hydro-Québec's thermal and nuclear generation directorate granted the firm R/D Tech a 15-year exclusive world licence to market the MÉTAR bracelet and its by-products. The device is designed to measure the thickness of the reactor's feeder pipes and was developed at IREQ in conjunction with Gentilly-2 personnel. The MÉTAR bracelet consists of a flexible collar mounted on a rigid frame which keeps a series of 14 ultrasonic sensors perpendicular to the surface of the pipe elbows to be inspected. A patent was filed due to the innovative nature of the device.

The bracelet was successfully tested during the plant's annual shutdown in the spring of 1999. We then optimized the device's design so that it would better meet the identified needs for improvement and qualify for inspection during the reactor's next scheduled shutdown in April 2000.

The MÉTAR bracelet thus improves reliability and accuracy in the measurement of the residual thickness of the reactor's feeder pipes. It also reduces the time required for inspections and, consequently, exposure to radiation. Once the technology resulting from this first phase of development is transferred to R/D Tech, we will work on the next generation, i.e. a motorized bracelet which moves independently along the reactor's feeder pipes.

High penetration wind/diesel combination: first commercial project

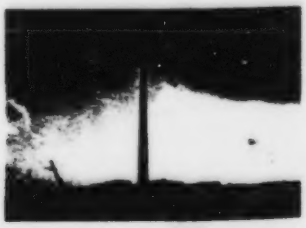
In May 1998, a joint-venture agreement was signed with Vermont-based Northern Power Systems for the first commercial project involving high penetration, no-storage wind/diesel (HPNSWD).

The technology, which was demonstrated at IREQ in 1990, was developed to reduce Hydro-Québec's operating deficits in its autonomous electrical systems; accordingly, the chosen scenario prioritizes wind energy. Optimal penetration of the HPNSWD system (the typical ratio for installed wind power/system peak demand is 150%) is established based on local economic parameters (cost of fuel and cost of installing additional equipment) and wind velocity.

Diesel is not used when the wind is strong enough to meet the power demand. The excess wind energy can be used to supply secondary loads, thereby reducing the amount of fuel used for heating. Frequency is controlled through a dump load which maintains a balance between supply and demand at all times.

This first commercial project was delivered to Tanagdusix Corporation, located on St. Paul Island in the Bering sea in Alaska. We performed the dynamic modelling of the system using the data provided by NPS and then drew up recommendations on the choice of electrical apparatus. We also supplied the frequency regulator which makes the high wind penetration possible and ensures power quality at a level at least equivalent to that provided with diesel power.

The full system was put into service in March 1999 and the technology transfer was successfully done in June. In fact, the installation allowed the client to reduce electricity costs by 35%.



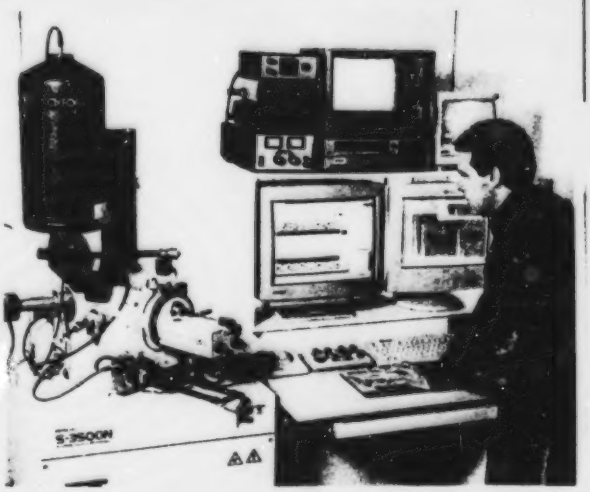
Combining two microscopes for the analysis of non-conducting samples

The purchase of a new scanning electron microscope (Hitachi S-3500 N) was the most important investment IREQ's materials characterization laboratory made in 1999. One of the features which distinguishes this microscope from the S-570 and S-4700 FESEM (Cold Field Emission Scanning Electron Microscope) is its variable-pressure mode of operation. The term "variable pressure" applies to scanning electron microscopes which can operate in both normal high-vacuum and low-vacuum mode. The main advantage of variable pressure is that all non-conducting and/or hydrated samples are directly imaged, eliminating the need for long and tedious sample preparation procedures. Nor is it necessary for the samples to be metallized.

In as natural a state as possible

With this mode of operation, the idea is to be able to observe the samples in as natural a state as possible, without modifying their surface area and without the artifacts produced by the usual sample preparation techniques.

With its original design that optimizes both modes of operation, the S-3500N is characterized by complete transparency for users, i.e. all of the functions available in one mode are also available in the other. In addition, all the parameters (e.g. enlargement, kV and working distance) are the same for both modes.



The vacuum system is entirely computerized, even in variable-pressure mode, so there is no need to manually operate a valve to obtain the desired working pressure or to regulate the pressure inside the specimen chamber during long work sessions to compensate for the degassing of the sample.

The S-3500N has a Dual-Bias system which increases the low-voltage emission current required when working at voltage levels under 5 kV. An emission current of 5 kV is thus obtained, the same as what is supplied by a typical 30-kV scanning electron microscope. Low voltage has the advantage of yielding a smaller volume of interaction, with images which are much brighter and a better signal-to-noise ratio than any other scanning electron microscope available on the market (with the exception of field emission microscopes such as the S-4700).

Lastly, the S-3500N is extremely user-friendly. It has the same user interface as the S-4700 and features the functions most commonly used by a microscopist, i.e. magnification, brightness/contrast, stigmators, and multi-function knob, all of which makes it very easy to use.

IREQ, it should be noted, is the only Canadian laboratory to combine these two microscopes for the analysis of non-conducting samples such as concrete.

R&D is a strategic focus for TransÉnergie. Innovation is at the core of our activities, whether transmitting electricity from our generating centres to the load centres, meeting the challenges of the market, commercializing the capacity of our system or dealing with the high-tech aspect of our field.

Hydro-Québec is a world leader in the high-voltage transmission of electricity. And we can maintain this position only if we continue to innovate and stay at the cutting edge of technology.

R&D allows us to identify and develop technologies which boost our success and hone the utility's competitive advantage. In this respect, 1999 saw a major research program aimed at protecting the transmission system under various climatic conditions such as ice storms. This work led to the development of de-icing techniques which are among the most promising solutions. Other R&D achievements helped improve the quality of our product and increase the capacity of our electrical transmission infrastructures.

Clearly, we must continue our efforts and do everything in our power to foster innovation. One of the objectives of our strategic plan for the next five years is therefore to maintain a level of R&D activity which reflects the expansion and continuity in service of our power system. This is also why we are actively working on implementing integrated innovation management within the utility. In this way, we hope to bring R&D more in line with our strategic and corporate objectives by systematically pooling the expertise of research teams and our own specialists. This approach should allow us to better manage our overall innovation, including actual R&D, technological monitoring, value-adding and venture-capital investments. This is how we will be able to make major technological breakthroughs that will have a major impact on our activities.

Jacques Régis
President – TransÉnergie

First pilot installation of MONITEQ III at the high-power laboratory

Last year, we conducted the first pilot installation of a MONITEQ III system on an 800-kV PK-type air-blast circuit breaker at the high-power laboratory. The installation will be under observation until June 2000 in order to detect and correct any operating problems. This work is the outcome of the optimization and industrialization efforts carried out in conjunction with Snemo, an electrical equipment manufacturer. Snemo already holds a marketing licence for the MONITEQ technology.

MONITEQ (continuous monitoring of high-voltage circuit breakers) is a key component of a policy on predictive maintenance. It reduces maintenance costs through timely detection of major anomalies. Using failure data, system operators can also carry out work on other in-service circuit breakers before a failure occurs.

First pilot installation on an 800-kV PK-type circuit breaker

The MONITEQ III system integrates the latest developments devised by the Hydro-Québec/Snemo team. We reduced the number of sensors and developed a new architecture to lower installation costs. In addition, the new electronic assembly, which meets the latest international standards, successfully completed all of the qualification tests including climatic and vibration tests and immunity to electromagnetic interference.

Moreover, to reduce the cost of burying the optical fibre used to link the local controller at the base of the circuit breaker to the central controller, the new system is now equipped with wireless technology which uses the 2.4-GHz bandwidth. Technologies developed to improve the product include one local controller per phase, a single printed circuit for the local controller's electronic components, and a fast-action connector linking all the sensors in a given phase to the local controller.

De-icing conductors by short-circuit current

During the 1998 ice storm, it was the weight of the ice on the conductors which caused Hydro-Québec's transmission towers to collapse. The de-icing methods used by some electric utilities, such as the heating of conductors or mechanical de-icing, are difficult to use for twin or quad bundle conductors, which means they cannot be used on our 315- and 765-kV lines.

This is why we have been testing a new de-icing method which uses electrodynamic forces, caused by the circulation of a short-circuit current, to knock the conductors against each other. Our tests in the winter of 1999 were more specifically aimed at minimizing the duration and amplitude of the short-circuit current required to de-ice the conductors.

The test program targeted a quad conductor bundle, typically found on 765-kV lines. Using a Cardinal-type bundle with a 91-m span inside IREQ's high-power laboratory, the ice was created on a 55-m subspan, i.e. between two spacers. To create the ice, mechanical and thermomechanical laboratory personnel developed an innovative method which consisted in slipping a cylindrical plastic sleeve of the required diameter (for a radial equivalent of 15 mm of ice) around each of the conductors and filling it with water. Once the water froze, the sleeve would be removed just before starting the short-circuit test.

To minimize the amplitude and duration of the short-circuit, the tests focused on excitation of the natural oscillation of the conductors; the motion of the conductors was emphasized so that they would knock together. They could then be de-iced with a lower current, about 12 kA asymmetrical. With the method, known as the de-icing by short-circuits synchronized to the resonance frequency of subspans, 70% of the ice can be removed from the conductors under certain conditions.

During the winter of 1999, a test program carried out on a 315-kV twin conductor bundle demonstrated that the method makes it easier to de-ice the lines; in fact, a 10-kA asymmetrical current is all that is needed to remove 70% of the ice from the conductors.

In 2000, TransÉnergie will conduct an in-depth study of our new method from two perspectives: the impact on power system stability and Hydro-Québec's customers, and network application strategies.

New corona ring

At the request of TransÉnergie and working closely with ABB, we developed a corona ring for the 765-kV DLVF circuit breaker.

We were aware that during switching operations on the XL-1 reactor with the Des Cantons substation line 700-1 circuit breaker a flashover had occurred in phase C of the 700-2 circuit breaker, which had remained open. Inspection of the circuit breaker showed clear signs of the bottom of the arc on the radiator fins in the main chamber. Since the fins have sharp edges, they may have triggered the flashover.

Decreases the probability of circuit breaker flashover

We thus analyzed the electrical field stresses using the PHI-3D software program and a three-dimensional representation of the geometry of a main chamber and a radiator fin.

We then developed a corona ring which decreases the electric field's impact on the fins, decreasing the probability of flashover. The ring reduces the electric field on two parts of the circuit breaker: the command insulator flange and the radiator.

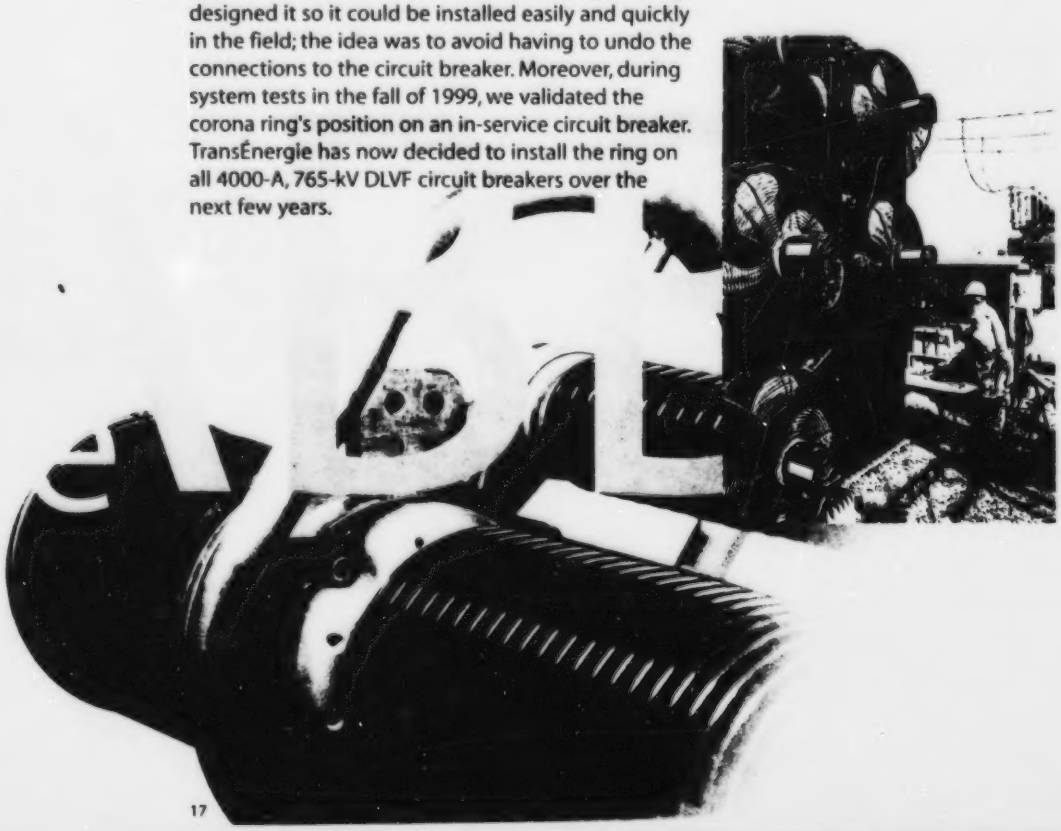
ABB, which was in charge of manufacturing the ring, designed it so it could be installed easily and quickly in the field; the idea was to avoid having to undo the connections to the circuit breaker. Moreover, during system tests in the fall of 1999, we validated the corona ring's position on an in-service circuit breaker. TransÉnergie has now decided to install the ring on all 4000-A, 765-kV DLVF circuit breakers over the next few years.

Industrial prototype for new direct-current blocking system

At the request of TransÉnergie, we recently developed an industrial prototype for a new direct-current blocking system for transformer ground neutrals. The device, which will be tested in the field in 2000, may be used as a protection system by TransÉnergie to ensure system stability as well as proper operation of power transformers exposed to direct current.

Direct current flowing through transformers can adversely affect the power system by generating harmonics, causing resonances, increasing the consumption of reactive power, and tripping protection systems. This phenomenon occurs during magnetic storms and can be caused by the ground electrode of a neighbouring high-voltage direct-current substation which operates in ground-return mode.

To counter this phenomenon, TransÉnergie has been using series blocking capacitors and series capacitor banks on the main transmission system. Wishing to have an additional protection device, TransÉnergie asked IREQ's specialists to develop a direct-current blocking system.



Much more compact and economical than the systems used in the field, the device consists of a 1-Ω industrial-frequency capacitor capable of withstanding a voltage of up to 1500 V at its terminals. The capacitor can block the direct current flowing through the transformer ground neutrals. The stand-alone system has a mechanism which interrupts the capacitor's operation for a half-second in order to let through major short-circuit and inrush currents. Data acquisition and standard telephone systems allow remote follow-up, and a mechanical disconnect switch ensures safe access to the device.

During laboratory testing, the device was subjected to 6500-A rms symmetrical currents, equivalent to 18,000 A peak, which represents the extreme fault current conditions which can occur in a substation. A Québec-based firm, Contrôle RL, was awarded the prototype assembly contract. This year, the prototype will be installed at Waterloo substation and subjected to a year-long series of tests to assess its operation under actual operating conditions.

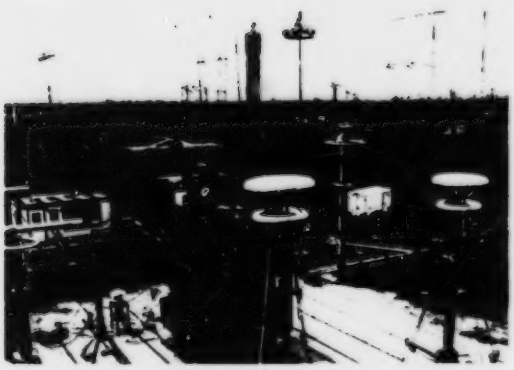
Maximizing the use of power transformers

Characterization of saturation losses in power transformers

In 1998, on behalf of TransÉnergie, we initiated a study on saturation losses in power transformers. The purpose was to increase our knowledge of power transformers so that optimal use could be made of them. In fact, additional saturation and instantaneous losses are virtually never discussed in the scientific literature. Though they tend to limit overvoltages in low-load systems, these losses are not accurately represented by current simulation models.

The aim of the first phase, which consisted of tests on small transformers with power ratings of 1 to 100 kVA, was to define the main study parameters. Then, in 1999 we carried out tests at the high-power laboratory on a 370-MVA single-phase transformer on the 735-kV transmission system. A voltage level of up to 1.4 times the nominal voltage was applied to the no-load equipment. Precise measurement of the voltage on each of the windings and the excitation current allowed us to characterize the losses in the equipment. We found that these losses substantially increase in relation to nominal losses if the equipment is in a state of saturation, especially overexcitation. After digitally processing the results a number of times, we developed a model which can be used with power-system simulation software: it is able to represent several conditions which occur on the power system and, with a few adjustments, can be applied to other types of transformers.

We also focused on the transformer losses which accompany phenomena such as inrush currents, direct-current flow, and harmonic voltages superimposed over the fundamental voltage. This year, we will continue processing the test results and fine-tuning the model.

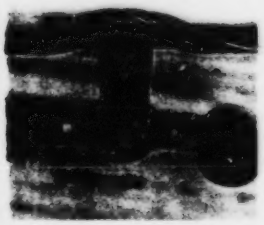


New developments in overhead systems

In Peru, IREQ's lines specialists designed and commissioned a major insulator monitoring station, including a remote data analysis system, in a polluted natural environment. The project was carried out for the Montreal-based engineering firm Dessau. Here in Montreal, we began research work with a view to commissioning an experimental distribution line.

For reinforcing distribution systems

The construction of this new line is part of a project aimed at strengthening the overhead distribution system. The aim of the project, carried out in conjunction with IREQ's major testing laboratories and Hydro-Québec's overhead distribution department, is to design an installation that will be used to directly evaluate models and simulation software.



Our R&D teams also conducted demonstration tests as part of a study aimed at assessing the performance of several non-conventional techniques for countering overhead-line vibrations such as subspan oscillations, galloping, etc. These tests thus allowed us to research, on behalf of TransÉnergie, various innovative devices such as phase spacers, dampers, and mechanical fuse links. This equipment, which will eventually be used on transmission lines, must be carefully evaluated. The work, which took place on the experimental line in Varennes, was carried out jointly with the Quebec firms which will be in charge of manufacturing the devices once certification has been obtained.

Lastly, one of our staff was appointed secretary of a new IEC international committee set up to study the electromagnetic effects of power lines.

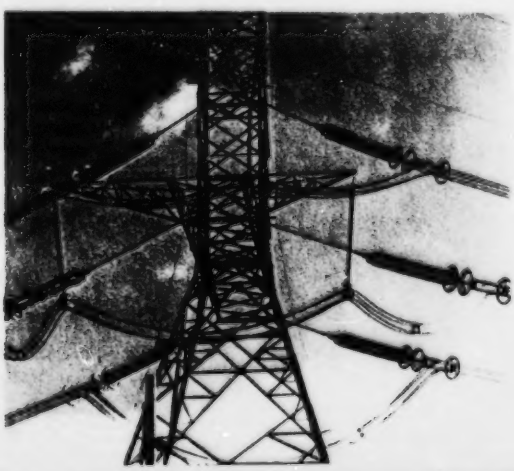
Climatic effect monitoring

Three new stations for the remote monitoring of mechanical loads on power lines were set up on Hydro-Québec's transmission system at the request of TransÉnergie. The stations are used to monitor changes in climatic loads, determine their scope, and establish historical trends based on different conductor configurations. They will be incorporated into the Sygivre measurement networks this year.

Another project, consisting of a thermal de-icing technique, was carried out in conjunction with the field-testing unit and TransÉnergie. We demonstrated the method's efficiency on the overhead ground wires of a 735-kV transmission line. The technique, which uses a direct-current mobile source, will be integrated into the transmission system in the winter of 1999-2000.

Also on behalf of TransÉnergie, we used demonstration tests to compare the efficiency of two techniques for de-icing energized substation equipment, notably 735-kV disconnect switches. Two techniques were assessed: dry ice projection and a new photonic de-icing device developed in our laboratories. Lastly, eight separate presentations on ice monitoring projects were made, jointly with the utility's various business units, at the annual conference of ACFAS (*Association canadienne-française pour l'avancement des sciences*) held in Ottawa in 1999.

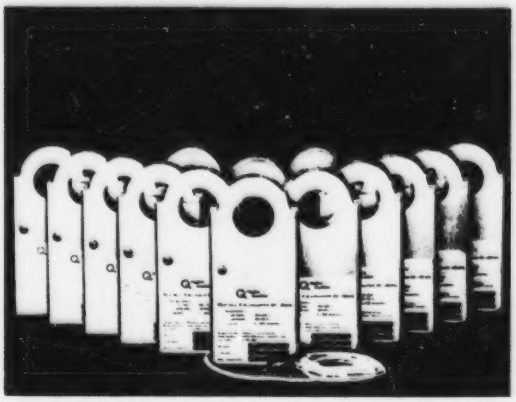
Our unit organized, jointly with INRS-Énergie et Matériaux, a major international conference in Montreal on lightning laser-triggering technologies. Delegates from six countries took part in the event.



New developments in underground systems

Thanks to the new device developed by a team of researchers from the transmission and distribution technologies department, we are now able to measure the temperature of the materials used in underground cables and transmit the data remotely. The device, which will undergo major testing later this year, resulted from the collaboration of researchers and technicians from the lines and systems software department, with the work being carried out at the request of Hydro-Québec's Distribution Group.

The U.S. group EPRI also enlisted our expertise for a project which involved assessing prefabricated vaults. The project team was required to identify problem areas and methods used to mitigate short-circuits in underground power cables.

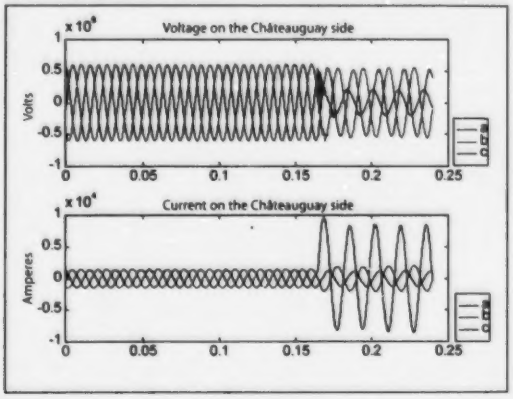


Our team also demonstrated that a technique which we developed with an American partner, UTIL-X, can be used to rejuvenate some underground distribution cables. This project was carried out on behalf of the Distribution Group's underground systems department. There are major benefits to using rejuvenation techniques for underground distribution cables which are fairly old; the financial benefits are substantial since the cables' service life can be extended at a much lower cost than if the cables were replaced.

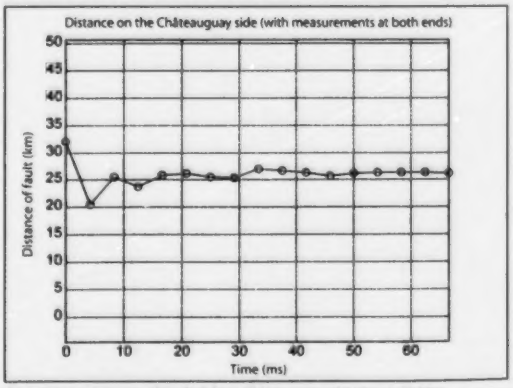
Precisely locating short-circuits on transmission lines

The cause of permanent short-circuits on transmission lines must be quickly eliminated to maintain an adequate margin of stability and restore service in areas without power. The conventional method for locating faults is to send patrol teams to inspect the entire line from the ground or by helicopter. This work becomes especially difficult in rugged areas, during inclement weather, and for lines which are very long or at a considerable distance from the load centres. This is why TransÉnergie asked us to develop a faster solution, based on the use of algorithms.

Voltage and current recorded on feeder 7038 at Châteauguay substation



Curve of the estimated distance of the fault with measurements at both ends of feeder 7038



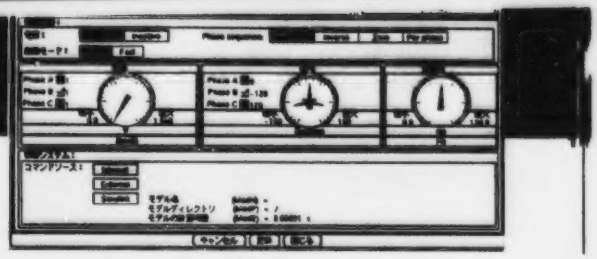
The estimated distance of the fault from Châteauguay substation is 26.2 km

We thus developed high-performance algorithms for locating short-circuits using digital fault recorder data. Digital fault recorders are new devices which Hydro-Québec has been systematically installing at substations to replace the old paper recorders. When a short-circuit is detected, they record the voltage and current signals at the start of lines and transmit the data to a central computer where the information is archived. The data are very useful for analyzing network behaviour and quickly locating short-circuits using IREQ's algorithms.

These algorithms, written in Matlab, have already been validated using EMTP simulations as well as recordings of actual short-circuits on the network. In 1999, we continued our work by converting C language functions and designing software interfaces to ensure compatibility with the client's analysis software. The final product took the form of a dynamic-link library which runs under Windows.

Locating short-circuits even faster

Initially, the software will be used by the experts in charge of power system behaviour, automatic controls and protection systems. It can then be downloaded and used by personnel in charge of regional planning and analysis. We are currently trying to solve the difficult problem of locating short-circuits on series-compensated lines and, as recent results are highly encouraging, we will soon be adding new algorithms to the library if the final results are conclusive.



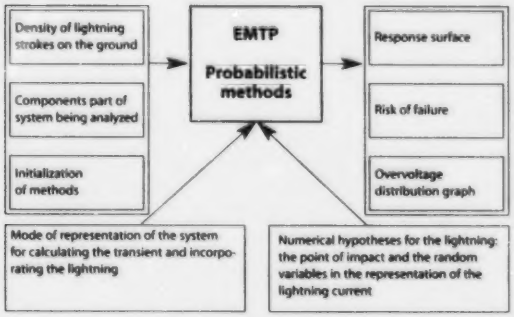
LIPS: new software for assessing the risk of lightning-induced failure in transmission system equipment

The research and prototyping work we carried out in 1999 on numerical methods and the analysis needs of transmission systems subjected to the effects of lightning have resulted in a partnership agreement with Électricité de France (EDF) and France Télécom (FT). The agreement involves the development, by the year 2001, of the Lightning Impact on Power Systems (LIPS) software program.

EDF and IREQ (on behalf of TransÉnergie) wished to have an EMTP-based (Electromagnetic Transients Program) software to evaluate the risk of lightning-induced failure in transmission system equipment. Moreover, such a program would allow France Télécom to study telecommunications networks and their interaction with electrical transmission systems.

Insulation for an electrical power system is chosen based on an acceptable risk of damage, in terms of both costs and operations. Though direct digital simulation of the behaviour of networks hit by lightning is useful because it allows the resulting overvoltages to be assessed, it is not enough. Assessing risk means taking the probabilistic nature of lightning into account. However, no tool exists that is sufficiently accurate and recognized worldwide for assessing the risk of lightning-induced failure in equipment.

The LIPS project, which aims to study both direct and induced lightning, is based on the pooling of the partners' resources and expertise. It will also benefit from the development of EDF's STCI software (*Station de travail de coordination de l'isolement* – insulation coordination workstation).


Density of lightning strokes on the ground
Components part of system being analyzed
Initialization of methods
EMTP
Probabilistic methods
Response surface
Risk of failure
Overvoltage distribution graph
Mode of representation of the system for calculating the transient and incorporating the lightning
Numerical hypotheses for the lightning: the point of impact and the random variables in the representation of the lightning current

Load modelling at TransÉnergie

Load behaviour has a considerable impact on power system transients. It is thus important that the stability studies which the utility conducts for power system planning purposes be based on the most accurate representation of load behaviour. These studies use the following exponential static model for the total load:

$$P = P_0 (V/V_0)^{np} (1 + Kp\_f)$$
$$Q = Q_0 (V/V_0)^{nq} (1 + Kq\_f)$$

Since the mid-1970s and until 1990, planning criteria were based on a factor of np = 1.3 and Kp = 0.7 for winter (from October 1 to April 1) and of np =1.0 and Kp = 1.0 for summer. In 1991, an analysis based on the LOADSYN software program confirmed the parameters for the total peak load in winter. During this time, in order to track load behaviour in real time, the TECC-I and TECC-II systems and power-system measurements were used to confirm the voltage exponent of the load models responsible for the LOADSYN decomposition. For various reasons, the TECC results have had few applications; in fact, since 1976, only slight modifications have been made to the load models used in power-system planning due to the fact that the models obtained from real-time tests are sometimes difficult to explain, and that a safety margin has to be incorporated in the studies.

Of prime importance for stability studies

Our load-behaviour study, carried out at the request of TransÉnergie, focuses on the various methods used to determine the active-load model and assesses the results. The conclusions are as follows:

- The nq values required for the stability software simulations cannot be reliably determined;
- The np coefficient of a load usually depends on the type and amplitude of the disturbance;
- The measured np coefficients and their rate of dispersion are highly dependent on frequency deviations;
- The np coefficients measured by TECC for disturbances under 2% are erratic;
- TECC and LOADSYN propose models in different frequency ranges;
- The parameters used for voltage oscillations ranging from 0.5 to 0.1 Hz are somewhere between these two models.

With respect to the modelling of the summer load, it appears that further characterization of the commercial and motor loads is required before the current model can be qualified as safe.

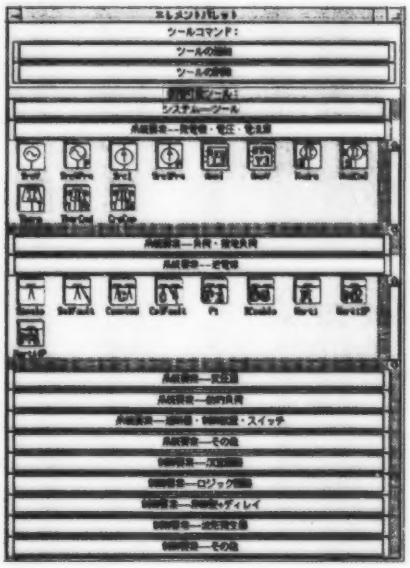
Japanese version of graphical interface

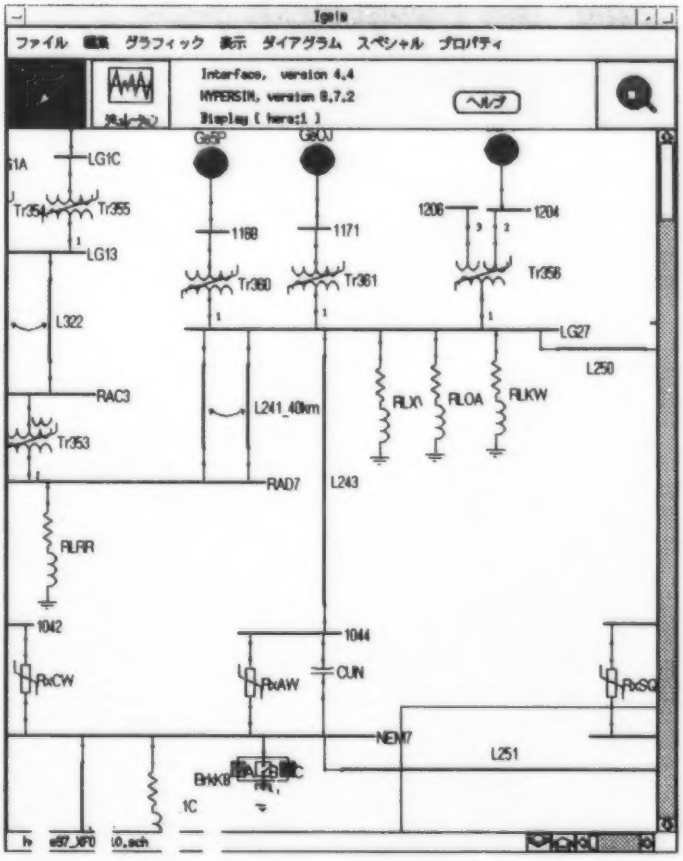
For the past few years, we have been working on developing the IGSIM graphical interface which includes a single-line diagram editor. This interface is part of the Hypersim simulation software developed by IREQ's power-system simulation laboratory and marketed by Teqsim, a subsidiary of TransÉnergie.

In 1989, we reached an agreement with Mitsubishi Electric, Hypersim's Japanese distributor, to deliver Japanese versions of the graphical interface and Spectrum graphic display software by October 2000. The objective is to train engineers from the Hokkaido electric utility.

The deliverables include an international version of the graphical interface and software; the use of Japanese characters will facilitate training. Various functions will be added for the instructor.

One of the advantages of our graphical interface is its adaptability. This new project will give us an opportunity to demonstrate what the software is capable of in the area of training.





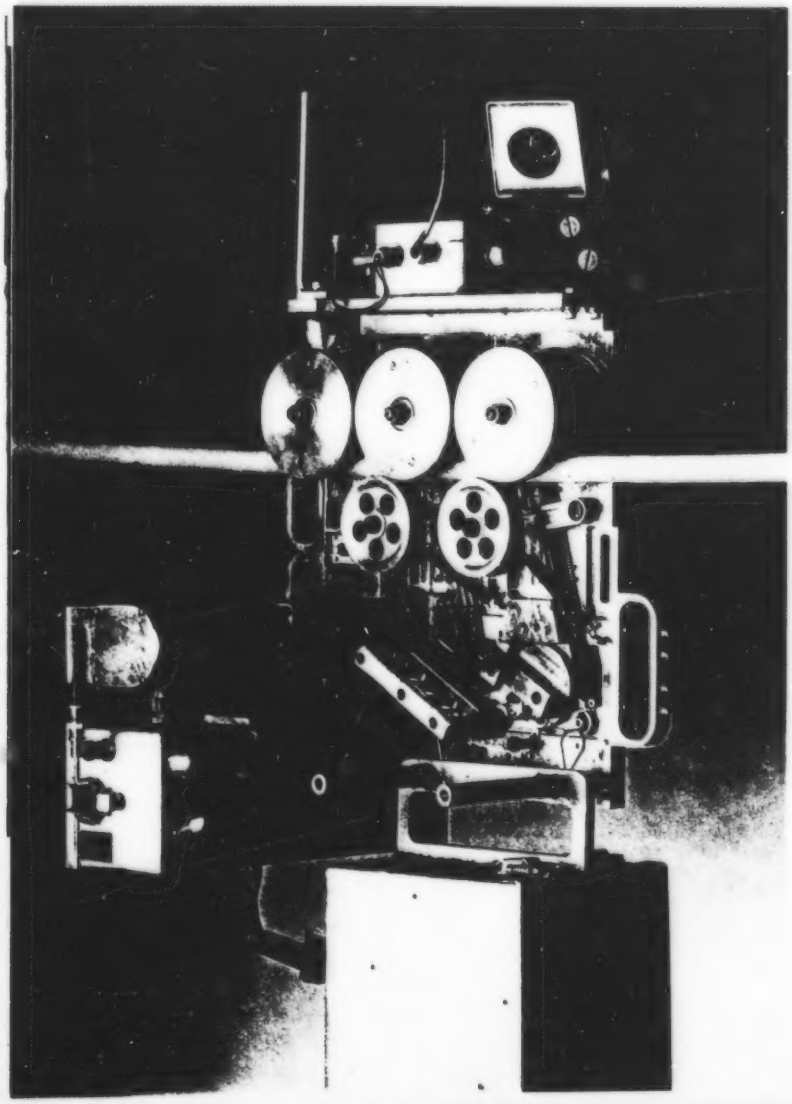
Multi-purpose trolley for live-line work

In order to design an emergency power-driven de-icer for cables and conductors, we first needed to design a lightweight, compact and sturdy trolley which could be operated from the ground. The de-icing tool, designed for TransÉnergie, consists of a set of blades mounted on a power-driven impactor which is then attached to the trolley.

We designed the trolley so that it could also be used for various transmission-system maintenance tasks. Our aim was to diversify our technology for live-line work. One of the preliminary developments, for instance, consisted in adding a multi-directional camera to the trolley. This camera gives a clear view of the installation's components so that anomalies can be detected during inspection. We also plan to use the trolley to inspect the condition of joint sleeves on conductors. In this case, a measuring device would be attached to it.

We found another use for the trolley, this time using the cradle-block method. Thanks to the trolley's pulling force on the cable, challenging tasks can be carried out. Because it is compact and lightweight, this tool is highly valued by line workers. We also tested its controls, which are capable of withstanding the effects of electric and magnetic fields, so that de-icing operations can be carried out on live conductors.

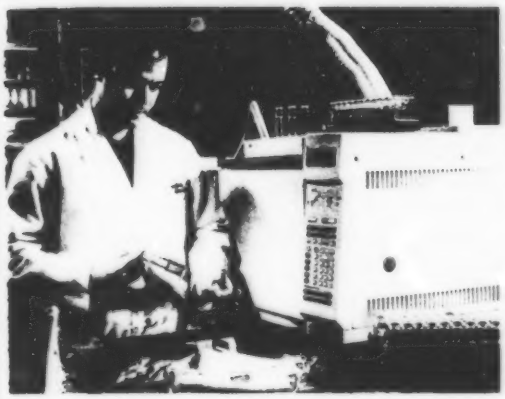
Designed for various maintenance tasks



Analysis of dissolved gas in insulating oil

From 1988 to 1995, as part of a joint project with Hydro-Québec's transmission equipment specialists (*unité Appareillage de transport*), we developed and validated a new method for the automatic analysis of insulating oil. It is known that by monitoring the gas content in the oil, incipient faults can be detected and action taken prior to the occurrence of failure. In fact, a transformer's electrical insulation largely consists of organic matter: the conductor coils, covered in insulating paper, are immersed in mineral oil which serves as a dielectric and dissipates the resulting heat. Under the effect of electrical or thermal stresses, long chains of hydrocarbons break and the paper insulation decomposes, creating gas which partly or wholly dissolves in the oil.

Our method, which is based on the headspace sampler method coupled with gas chromatography (HS/CGC), is used to extract and analyze dissolved gas in insulating-oil samples. In 1995, this technique was transferred to the Jeanne-D'Arc laboratory and the Trois-Rivières electrical maintenance centre and has since been used to carry out routine dissolved gas analyses for Hydro-Québec's regions.



Following this technology transfer, we attempted to find ways of improving the analyses, more specifically by studying blood-testing techniques. Using just one sample, our goal was to analyze a series of tracers using only one intervention and a single measuring device. In 1999, after modifying the initial system, we validated the technique so that water could be measured in the same analysis sequence as the dissolved gas. The water content in the oil is a major parameter for the insulating paper which can affect the dielectric withstand of the oil. As the technique is now validated, we will transfer it to our regional laboratories this year to allow them to combine two types of analyses using the same sample and measuring device. For our part, we intend to continue our research so as to include in the analysis new compounds obtained from the degradation of the paper insulation.

Knowledge management and technology monitoring

Since 1996, in conjunction with Hydro-Québec's Sales and Customer Services Group, IREQ has been conducting research and development work aimed at devising an experimental knowledge representation tool. The aim is to study various ways of capitalizing on knowledge and transferring know-how and technologies. The objective is to turn the utility's know-how into a tangible asset, which means providing better access to such know-how and shorter lead times between the product's creation and use.

The research had three focuses: knowledge representation and processing; the end uses of a knowledge management system; and the interfaces used for knowledge manipulation, modelling and restoration.

Last year, we developed VIGITECH, a technology watch system used in a cooperative working environment which involved three staff members: a librarian to do data bank bibliography searches and order books and articles; a monitor who, in addition to his monitoring activities, analyzed the results and did syntheses on specific subjects; a client interested in one or more subjects; and a technology watch manager to coordinate the entire process. The manager was responsible for selecting monitoring topics, assigning tasks to monitors, and deciding when to transmit technology watch bulletins to clients.

We also developed a specialized interface to model and make dynamic use of know-how based on formal methods, such as MKSM, with a browser.

Our system has already attracted the interest of one of Hydro-Québec's business units (*unité Orientation et Intégration des projets de développement*), which intends to install the tool on its Intranet site during the course of the year. The knowledge modelling tool will be validated to support the process of setting up technological innovation portfolios and Montreal's École Polytechnique will use the knowledge management environment to implement training sessions.

> The utility's knowledge becomes a tangible asset

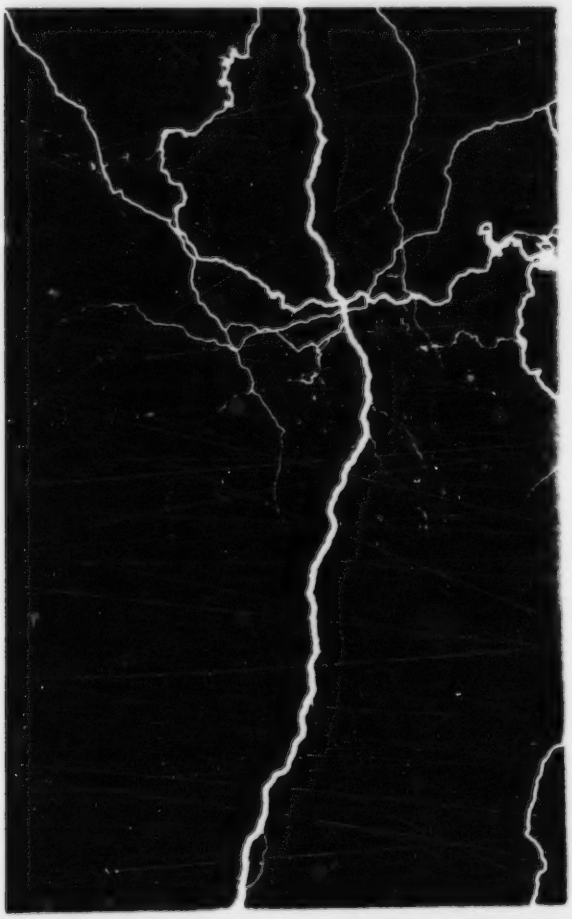
I consider 1999 to be a milestone year in research and development. It is true that major projects were realized in the area of distribution, but what I consider to be more important are the efforts that were expended on implementing an integrated innovation management process. This will bring R&D back in line with our core concerns and allow us to make R&D crucial to our success.

R&D and innovation needs with respect to distribution are substantial. Through their work, IREQ's researchers have naturally always helped ensure the reliability and safety of the overhead and underground systems, thus allowing us to better manage and control equipment by more fully understanding its behaviour. R&D has also helped us implement safe and environmentally-friendly techniques in distribution system maintenance.

But R&D results must, in my opinion, go a step further. It became crucial to direct our efforts toward attaining specific objectives. We also needed to pool all of the know-how in technology development to ensure that the end result would be implementation within the utility or outside commercialization. We needed to make R&D synonymous with added value. And this is the aim of the new innovation management framework.

The strategic objectives of the Distribution Group for the next five years involve major challenges. R&D's contribution is crucial if these challenges are to be met decisively.

Roger Bérubé
Vice President – Distribution



Improving the withstand of distribution transformers to counter the effects of lightning

Faced with the high rate of lightning-induced transformer failures on Hydro-Québec's overhead distribution system despite the fact that the transformers are equipped with lightning arresters, the Distribution Group asked us to determine the origin of these failures, which cause outages and equipment failure, and to suggest ways of improving transformer design. The project was initiated in 1996.

After an in-depth review of the technical and scientific literature, we analyzed 141 damaged transformers, 35 of which were equipped with lightning arresters. We noted that they were all damaged at the low-voltage end of the primary winding. Ten transformers from Hydro-Québec suppliers were then subjected to full-scale tests at the high-voltage laboratory: five of them failed and in each case the failures occurred at one end of a primary winding. We also conducted a behaviour study on two transformers – one rated 25 kVA and the other 100 kVA – subjected to high-frequency signals in order to measure the voltage distribution inside the primary winding.

Low-cost methods for countering failure

We were able to define two main failure modes: one was due to the induction of a high voltage in the primary winding, caused by the flow of current in opposite directions in the secondary windings; the second was due to the speed of certain phenomena which alter the uniform distribution of voltage over the primary winding and create resonances which cause high overvoltages.

VA TECH (Ferranti-Packard) and ABB were informed of the test results obtained on their equipment. They assisted us in locating the faults and in a new series of tests which involved injecting with their sources currents in the opposite direction in the transformers' secondary windings.

In light of these results, the project team identified cost-efficient ways of countering these failures, either by reinforcing the insulation at the ends of the primary winding, or by modifying the winding's configuration.

In 2000-2001, we will once again be requiring the assistance of the transformer manufacturers to help us identify the best solution and, if needed, in drawing up new test methods for validating the withstand of overhead distribution transformers. These methods will incorporate the failure data gathered during our study.

Diagnostic and measurement tools for live-line work

Live-line work on the distribution system has the advantage of decreasing maintenance costs while maintaining service continuity. However, this kind of work requires specialized tools and equipment which are completely safe to use. The Distribution Group thus joined forces with IREQ to develop a whole range of reliable, high-performance and customized diagnostic and measurement equipment.

For the overhead distribution system, 1999 was a milestone year since after several years of R&D work on various devices, we manufactured and delivered 30 VIS-300 devices for checking suspension insulators and 14 VAT-2000 devices for detecting the absence of voltage with reference to the neutral. The two devices should be installed on the distribution system early this year.

The VAT-2000 is a device which measures the absence of voltage for medium-voltage overhead distribution systems up to 25 kV. It is a unique diagnostic tool capable of unequivocally detecting voltage and determining whether the voltage is induced or real. The VAT-2000 also includes a precision voltmeter and is thus of interest to operations staff wishing to characterize the voltage throughout the system.

A range of reliable and high-performance equipment

For its part, the VIS-300 device was developed to verify, *in situ* along a string of defective insulators, whether the insulation is sufficient to safely replace a component of the energized string.

With respect to the underground system, we finished developing a new RTM-600 device for determining phase rotation. The device, developed for the 600-V low-voltage distribution system, displays the phase rotation when applied directly to the cable's insulating sleeve. Designed mainly to provide optimal safety for workers, it prevents line personnel from having to handle the bare parts and eliminates any risk of injury. So far, we have already delivered two preproduction RTM-600 units to Hydro-Québec's Distribution Group.

Furthermore, we are continuing our R&D work on the new DTRS-100 voltage detector designed for the medium-voltage underground system. To determine the absence of voltage on an underground cable, the new device takes a measurement on the semiconducting sleeve with a reference to the neutral.

Faced with ever-growing requests from the Distribution Group and given the device's commercial potential, we began to look into the possibility of establishing partnerships with manufacturers. A partnership agreement is currently being negotiated for the VAT-2000 and DTRS-100 devices, and we hope to find a partner for the VIS-300 and RTM-600 later this year.

Interactions and self-excitation of synchronous and asynchronous IPP generators

To integrate asynchronous and synchronous mini generating stations belonging to independent power producers (IPPs), certain modifications had to be made to Hydro-Québec's 25-kV distribution system. Hydro-Québec's Distribution Group had established stringent standards and guidelines which it updated periodically to meet the requests of IPPs and the planned power system development. Before revising its integration criteria, the utility had asked us to conduct a detailed analysis of the electromagnetic phenomena likely to have an effect on power system behaviour if the same feeder had synchronous and asynchronous generators, a situation not covered by existing standards.

Decreasing the cost of integrating independent power

Phenomena which present a hazard to workers and equipment include the self-excitation of asynchronous generators islanded on a local load as well as overvoltages during severe faults with opening and reclosing. Harmful interactions between synchronous and asynchronous generators must also be monitored as they can lead to major power swings and voltage oscillations, or even dynamic-state instability.

In 1999, four typical distribution system configurations, whose characteristics had been defined in conjunction with the client, were tested on *Power System Blockset*, the new power system engineering software developed at IREQ and currently marketed by the utility's subsidiary TransÉnergie Technologies and the U.S. company Mathworks. To analyze the effect of each major parameter (speed and voltage control, reactive compensation, power system load level, etc.), we conducted over 500 simulations, notably the interactions between two induction generators and a synchronous machine during various faults, by incorporating a full representation of the machines and transformers, including saturation. To our knowledge, it was the first study of this scale to be done on the distribution system using three-phase representation software.

Our study demonstrated that the criteria in the current standard encompass all of the operating scenarios so that the power system is provided with safe and conservative protection. One of the project's results was to pinpoint the constraints which can be loosened once the phenomena which are the most hazardous to equipment are known. Over time, these improved standards, which will modify protection procedures, will also decrease the cost of integrating small power production. Since our simulation tools are more complete, the distribution-system engineering studies conducted prior to the integration of large-scale generation should take much less time.

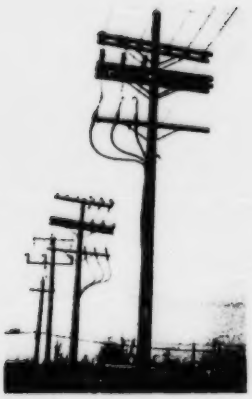
Modelling of distribution system losses

Distribution system losses account for about half of total losses recorded between the generating station and the customer's home or installations. Our objective is to determine ways of reducing these losses.

Models used up till now as part of optimization tools are aggregate models that have not been validated through measurements, or detailed models of the distribution system. Hydro-Québec's Distribution Group, on whose behalf this project was conducted, wished to validate the loss calculation models used by these software programs. Accordingly, in 1999 we conducted a measurement campaign on a distribution feeder.

Techniques to minimize losses

The chosen feeder, an Acton Vale distribution line, had some of the required characteristics: customers located only at the end of the line, the possibility of high load, and easy access to the installations. Testing required the cooperation of several IREQ units, the client, and the regional areas.



The tests spanned three months, from September to November 1999. To measure the losses, we had to install acquisition systems at both ends of the line, then synchronize them on a common time base. Over the space of five weeks – with one week used for calibration – we were able to gather voltage, current and phase displacement data and assess the system losses on the main distribution system.

This measurement campaign will help us validate the models before moving on to the next stages, which consist of breaking down the distribution system losses (related to transformers and the secondary distribution system) and proposing methods for minimizing them.

Development of a polymer additive for wood treated with chromated copper arsenate

For many years, Hydro-Québec had been using wood poles treated with the preservative pentachlorophenol (PCP). Following pressure in the early 1990s to ban the use of PCP, we evaluated the performance of other options available on the market. These formulations were for the most part based on chromated copper arsenate (CCA), to which various additives were added to counter the hardening of wood caused by CCA. Our research showed that the effectiveness of these additives varied and did not last long. After conducting intensive research, we developed an innovative additive which reduces hardness in CCA-treated wood poles.

The additive, a water-soluble polymer, is injected under pressure into the wood and then polymerized, to form a three-dimensional network which is water-insoluble. It maintains a higher rate of moisture in the wood, permanently reducing the wood's hardness. We filed various patents for the product, with other patents pending.

Since the fall of 1998, we have been taking part in a pilot project funded by Hydro-Québec's Distribution Group. As part of this project, we installed and treated 40 poles on the distribution system as well as on IREQ's premises in order to evaluate their performance under actual climatic conditions, i.e. outdoors.

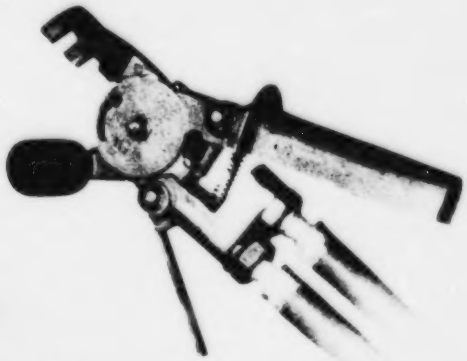
We attempted, in conjunction with another Hydro-Québec research team (*unité Valorisation de la technologie*), to sound out whether our additive would be of interest to companies specialized in the development and marketing of preservatives. Last fall, we signed a partnership agreement with the U.S.-based firm Hickson to jointly fund the additive's development and market it by the end of 2001. A budget of $1.3M has been allocated for the project, which is jointly funded by Hickson and Hydro-Québec's Distribution Group. The aim of the project, which will take place at our facilities and Hickson's, is first to reduce the cost of the additive by optimizing its chemical composition and the conditions under which the wood is impregnated, then to characterize the performance of the chosen formulation based on two factors: the hardness of the wood and its resistance to inclement weather. Note that the product development process goes hand in hand with a unique management process, which ensures that various aspects such as sales and marketing, R&D, regulations, toxicity and risk, manufacturing, funding, and planning are studied simultaneously. Lastly, another feature of the approach we used in developing the new product is that five decision points were used. This ensures that various aspects such as sales and marketing, R&D, regulatory framework, toxicity and risk, manufacturing, funding, and planning, can be studied concurrently.

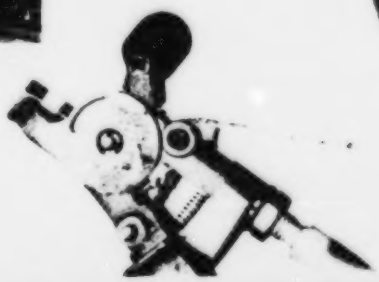
An additive which reduces pole hardness

New low-voltage grounding clamps and an innovative design for inspecting manholes

A partnership agreement for the production and marketing of new low-voltage grounding clamps was signed with the firm Hydrocom in October 1999. The company, a division of MacLean Power Systems based in Châteauguay, Québec, is specialized in the design, manufacture and distribution of products for electrical utilities and communications firms. The commercial version of the clamps, developed at IREQ, may be marketed toward the end of the year 2000. Tested at IREQ's high-power laboratory, the clamp successfully passed simulation tests under both regular and extreme operating conditions. The new clamp is remarkably safe: it is easy to install and firmly attached, which will reduce the hazards of live-line work and the cost of de-energizing the lines. The clamp is mounted on 2/0, 4/0 and 477 mcm thimbles, the standard size for distribution system transformer conductor thimbles.

Our other project, on behalf of Hydro-Québec's Distribution Group, involves replacing fuse boxes. We developed a system for the visual inspection and cleaning of switch pressure gauges and other manhole equipment. The system's efficiency and innovative design allow quick and safe preliminary inspections to be done, without opening the grating, before sending out a crew of six to eight workers to replace the fuse boxes. This means that the job does not have to be cancelled if the pressure gauge is not visible or indicates a hazardous situation. The preliminary inspection also ensures that the work will be carried out as planned, which is cost-effective; as part of this project, 1,700 manholes will be inspected. Note that this method can also be used for other types of work.





As a distributor of electricity, Hydro-Québec is committed to maintaining the rate freeze until 2002 and to keeping rates stable in subsequent years. Such stability requires strict management with a focus on increasing our efficiency on a continuous basis. The utility also intends to improve the quality of its service. For us, this means improving the products used in electricity applications, such as water heaters, electronic thermostats, convectors and dual-energy heating systems, and proposing customer programs aimed at replacing or adding to existing electrical equipment. R&D and innovation are key to achieving this goal, which is why the Sales and Customer Services Group is working with LTEE and counting on its input.

The implementation of the new innovation management approach within the utility will undoubtedly consolidate the close relationship with LTEE, making it a real partnership by establishing closer ties between our specialists and researchers. Moreover, involving our specialists in technology value-adding and venture capital in this process ensures that all aspects of R&D will be covered. This pooling of expertise and know-how will permit us to better identify projects which will help meet our customers' needs in terms of performance, efficiency, cost-effectiveness, after-sale service, etc., as well as ensure our competitiveness. It should also help maintain a good balance between our short-term and long-term needs.

Ghislaine Larocque
Vice President – Sales and Customer Services

The directorate in charge of major customer accounts (*direction principale – Ventes grandes entreprises*) is working closely with LTEE's specialists in order to develop technologies and electrical processes for energy-intensive industries. Carried out jointly with manufacturers, this work reflects the needs expressed by industry and always involves in-plant application. Recent projects include the development of a new efficient and cost-effective process for treating paper mill sludge. This highly promising technology will soon be used in a pilot installation to demonstrate its industrial capacity. The post-processing mixture has high added-value potential, which is of additional interest to manufacturers.

Other work in the last few years led to the use of electrical rather than gas-powered equipment in mines, thus reducing energy costs associated with ventilation equipment. The combined efforts of LTEE and our experts also led to the implementation of high-efficiency motors in plants, which are more durable and energy efficient. The widespread use of these motors in Quebec and throughout Canada has spawned a manufacturing industry which also uses LTEE's testing facilities.

R&D has proven that it can be a sizeable asset with a significant impact. In addition to leading to the implementation of technologies which enable the industrial sector to benefit from efficient and cost-effective use of electricity, it also fosters customer loyalty and boosts sales. Our practices are part of the new innovation management approach being implemented at Hydro-Québec. This approach centres on conducting well-defined R&D projects and making use of the know-how required for technology development. We thus intend to pursue our efforts to boost sales, increase our market share, and provide industry with first-rate service.

Richard Aubry
General Manager – Sales – Major Customers

Assessing the actual performance of decentralized generation

Fuel cells and micro-turbines

Over the past few years, there have been major technological developments in the area of decentralized generation technologies, especially fuel cells and micro-turbines. In 1999, several manufacturers began assessing the performance of their pre-production units and marketing new products. The technological monitoring conducted by LTEE back in 1998 had revealed that the emergence of this new field would have a substantial impact on Quebec's electrical industry.

In order to develop know-how in this area and better evaluate the potential impact of these technologies on the energy market – both in terms of risks and of opportunities – we launched a new project. Our studies have mainly focused on energy systems which use fuel cells, based on operating environments that are as realistic as possible. Last year, our work centered on providing LTEE with the required software and hardware tools and assessing potential applications and related markets here in Quebec.

Activities carried out in 1999 include:

- An initial evaluation of scenarios involving the use of fuel cells to partially meet the energy requirements of homes, apartment buildings, institutions, businesses and industry.
- A joint-venture agreement with the *Institut de recherche sur l'hydrogène* of Université du Québec à Trois-Rivières for the creation of a test installation to study independent energy systems which use hydrogen as a storage energy vector.
- The design and start-up of a test bench at LTEE which uses a 30-KVA alternating-current dynamic load to simulate the behaviour of real loads. We will also evaluate the actual performance of decentralized generation technologies and study electrical phenomena related to this type of installation.
- The acquisition of a micro-turbine and a fuel cell along with its fuel processing unit.

In 2000, we will conduct more detailed studies of the best scenarios defined in 1999 by refining the models used, adding scenarios based on micro-turbine use, and incorporating the performances measured on the test bench which will be commissioned at LTEE. We also intend to conduct field tests on the equipment.

Combining short wave infrared with snow-removal techniques

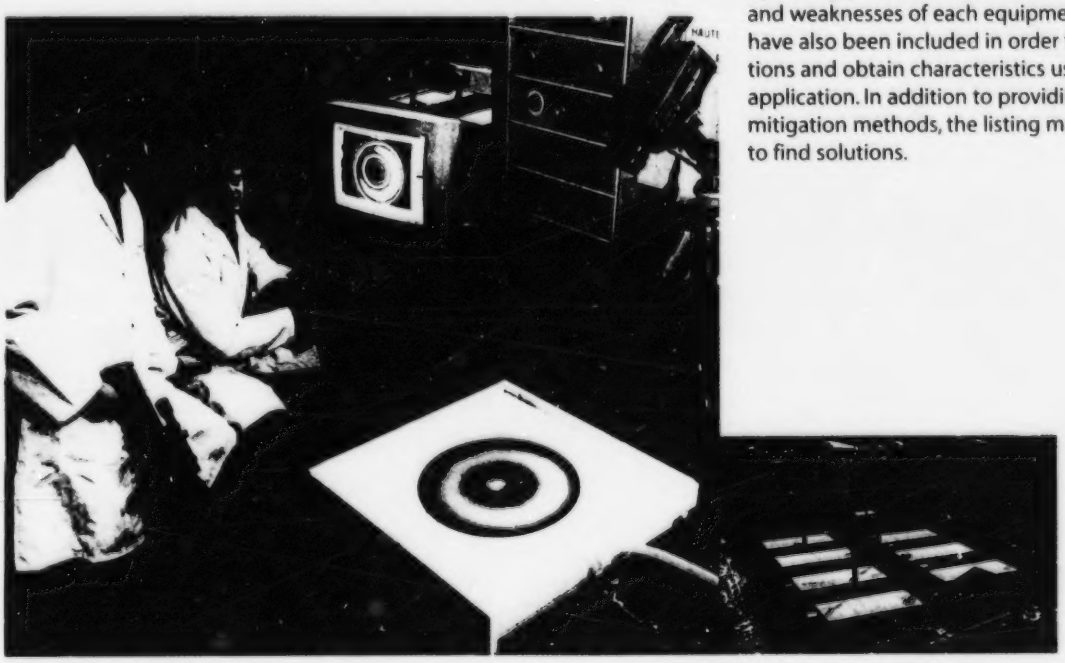
To help Hydro-Québec boost its electricity sales while meeting its customers' needs, LTEE is conducting research and demonstration projects on various high-potential techniques, such as snow-removal techniques. The applications of electric snow-removal techniques in Quebec, where the annual snowfall is about 2 m, are numerous and include roofs, handicapped ramps, sidewalks, driveways, and stairways. For reasons of safety, environmental protection, cost-effectiveness and quality of life, such methods offer a viable alternative to mechanical techniques. Our work is aimed at developing and testing optimal snow-removal techniques for various types of applications. Thus, in 1999, in order to assess various techniques, such as short wave infrared, we designed a test bench to carry out demonstrations under actual conditions.

Short wave infrared also has many other applications. For instance, since it emits radiative heat, it provides localized and comfortable heating, paving the way to numerous other applications, such as the heating of decks, work areas, bleachers and entranceways, and the de-icing of air inlets. LTEE is currently conducting various demonstration projects under actual conditions for several of these applications.

Electromagnetic compatibility and drive power

This year, LTEE focused on finding ways to improve the susceptibility of electrical equipment to voltage dips. To do so, we assessed emerging mitigation technologies on our electromagnetic-compatibility test bench. A series of tests were carried out on prototypes and commercial units from four manufacturers on behalf of Duke Power; the aim of the study, conducted at the request of EPRI, was to develop a test procedure for IEEE Std 1159.

Still in the field of electromagnetic compatibility, we drew up a list of mitigation solutions at the request of Hydro-Québec's sales and customer services group. The list includes generic options which are available or under development: it presents the operating procedure, characteristics, and strengths and weaknesses of each equipment group. Tools have also been included in order to compare solutions and obtain characteristics useful to a given application. In addition to providing a table of mitigation methods, the listing makes it easier to find solutions.



Another electromagnetic compatibility problem is related to the starting up of heavy-duty motors. In fact, due to the high startup current, these motors cause voltage variations which vary in intensity depending on the impedance of the power supply. We also studied startup methods which maintain a high torque while drawing less current. We retained one method: the fast-switched capacitor bank. Using capacitors laid out on different levels and tripped in sequence as the reactive power decreases, the voltage variations can be reduced to an acceptable level. Laboratory tests have demonstrated the performance and feasibility of this method.

Moreover, the *in situ* measurement of electrical motor performance must, to receive widespread acceptance, be as unintrusive as possible. We continued our prospecting activities to cover operation under non-optimal conditions, such as those found in industrial environments. We began to study the operating conditions with variations in load and supply voltage, including imbalances and harmonics. This study makes use of LTEE's variable-speed drive test bench, which can be used to simulate actual industry operating conditions. The dynamic brake, combined with the high-power amplifier and real-time measurement and calculation installations, were used to reproduce plant conditions in a laboratory setting.

A broad range of mitigation solutions

Electrotechnologies: high-frequency curing and recompression

In 1998, LTEE began to develop new electrical processes for industrial applications. Last year, several milestones were passed.

In the area of prepared meats such as sausages and hams, our tests showed that a few minutes of high-frequency curing was enough to produce quality meats. This method has many advantages for meat-product manufacturers in terms of raw-materials yield, ease of operation and handling, and sanitation. Carried out in conjunction with the *Centre de recherche et développement agroalimentaire* (CRDA), the project demonstrated the control of parameters for the design of applicators, thus paving the way to continuous high-frequency curing. This year, our main objective is to demonstrate the feasibility of this curing method. Once this objective has been attained, we will look into the possibility of commercial development.

Duke Power

We also evaluated several mechanical vapour recompression (MVR) applications. For instance, we researched the concentration of organic sludge, which is very difficult to press. We identified methods whereby MVR could improve the cost-effectiveness of activities related to the treatment and disposal of this type of sludge. We will be validating a number of technical aspects during the year and, if the tests are conclusive, MVR could be used for such applications as the treatment of secondary sludge from paper mills.

Still for the pulp and paper industry, we designed, built and tested prototypes as part of the development of a high-intensity infrared emitter. The thermomechanical withstand of some materials identified in 1998 allowed us to reach target operating temperatures and validate the proposed design. This year, we will carry out longer-lasting functional tests which will help us characterize the prototype's long-term performance.

Advantages in terms of raw materials yield

Support for the implementation of electrotechnologies

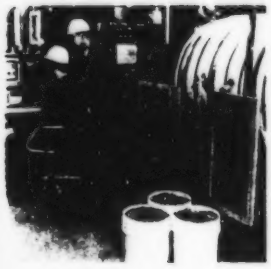
For over two years, [illegible]en providing technical support for Hyd[illegible]. Electrotechnology Implementation Assis[illegible]ogram, a commercial program which helps small- and medium-sized companies implement and optimize electrotechnologies in their manufacturing processes. Last year, LTEE carried out 140 projects among various companies. Three types of activities are available: technical feasibility studies, process measurements, and technical and economic analyses. LTEE's services are in high demand and have increased by over 50% compared with 1998, the first year the services were offered.

The feasibility studies conducted by LTEE on behalf of the participating manufacturers have two objectives: demonstrate the quality of the products developed using electrotechnologies and specify the preliminary design parameters for industrial equipment. The spinoffs are proven: the work, which was conducted at both the Shawinigan laboratory and the clients' plants, has led to the implementation of several electrical processes.

New process for treating paper-mill sludge

As elsewhere in the world, sludge management has become a major environmental problem in Quebec. Each year, close to 5 million tonnes of sludge are produced by the pulp and paper industry, municipalities and from pig slurry. Moreover, the conventional techniques, incineration, burial and landfarming, are no longer viable because of the costs involved, the lack of available land and operational problems.

To find a solution to the problem, Hydro-Québec, through the joint efforts of two project teams, developed an electrical process which completely destroys sludge with a minimum organic content of about 20%. The new technology, known as plasma-activated wet oxidation, is based on the application of a plasma-arc torch and consumes only 100 kWh per tonne of sludge. Another noteworthy advantage is that it reduces by a factor of 20 the volume of ash with a high conversion potential and gases with an environmental impact comparable to that of burial.



Despite these advantages, however, a preliminary business plan carried out by LTEE has shown that the technology's commercial potential in Quebec is not very high over the medium term, due to the low cost of eliminating sludge, the regulations currently in force, and the fact that the process requires 2 to 3 MW of additional power. On the other hand, the potential for the rest of North America is excellent; based on conservative market estimates, we expect to be able to sell about 40 units for a total of $120M. In fact, negotiations are already under way with well-known equipment manufacturers with a view to marketing the technology.

Enhancing the performance of electrolytic cells

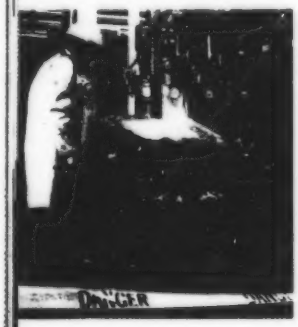
Noranda's CEZinc plant is one of Hydro-Québec's major customers. A leader in its field due to its production capacity, CEZinc consumes some 750 GWh per year. However, the company has been experiencing a problem which affects the performance of its zinc plants, namely aging of the electrodes used to produce the zinc by electrolysis. The resulting short-circuits have reduced production and increased costs. To solve the problem, we conducted research in conjunction with the Noranda Technology Centre, CEZinc's research centre. LTEE and IREQ carried out the study for Hydro-Québec's sales and major accounts department.

The laboratory results that were obtained confirmed our understanding of the mechanisms involved in the deformation of the electrodes, which allowed us to back up CEZinc's decision to increase the number of anodes in the cells by 10%, without increasing short-circuits or production costs. This decision not only enhanced the performance of the electrolytic cells, but the project also led to an increase in sales of about 60 MWh/year, a beneficial outcome for Hydro-Québec. This study has paved the way for other collaborative ventures between Hydro-Québec and its major industrial customers in the metallurgical industry.

Low energy consumption

A high-power lithium-polymer battery for hybrid vehicles

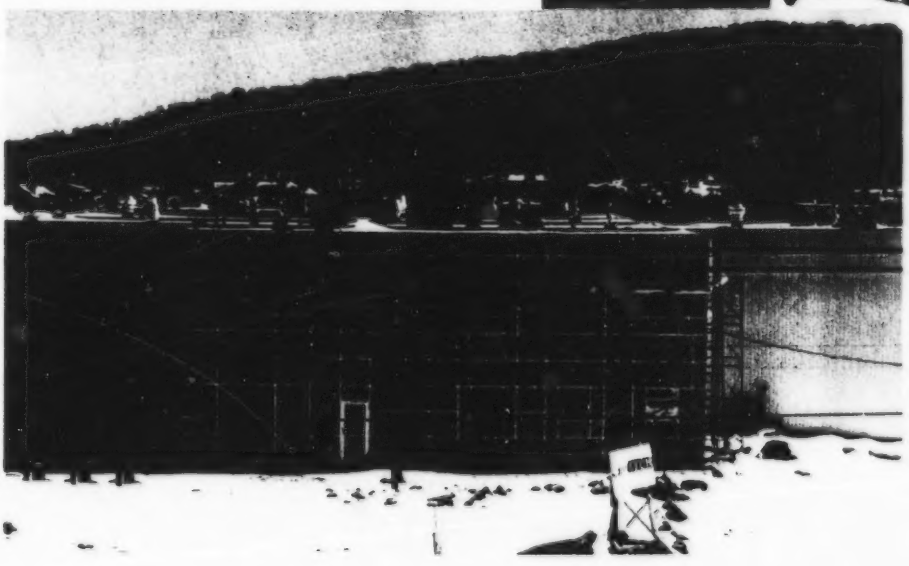
For the past 20 years, Hydro-Québec has been working on lithium-polymer batteries (LPB) for electric vehicles (EVs) and has invested some $96 million in the technology. In 1993, the utility joined forces with the U.S. firm 3M to continue the development of state-of-the-art technology. The project was funded by the United States Advanced Battery Consortium (USABC). In 1994, the Boucherville-based firm Argo-Tech, a wholly owned subsidiary of Hydro-Québec, was created. With its 125 employees, it produces lithium-polymer batteries and intends to market the technology in the future.



In 1997, alongside these developments, Hydro-Québec undertook to design a high-power battery for hybrid electric vehicles (HEVs) based on the LPB technology. The main objective was to boost the battery's power by increasing its active surface and creating thinner components. After promising results were obtained during a first contract with General Motors, we were awarded a $1.2M contract in relation to the Partnership for New Generations of Vehicles (PNGV), the most ambitious program ever for hybrid EVs in the United States. The agreement, which is being administered by Hydro-Québec's subsidiary Argo-Tech, involves an initial 9-month phase which should be completed by the end of the summer of 2000.

The contract has three main objectives: improve the electrochemical performance and reproducibility of the current configuration of HEV batteries; improve the electrochemical and chemical stability of the separator and cathode; and identify the key elements of the manufacturing process and the materials required to attain the PNGV program's cost, weight and performance objectives.

Phase II, which will be initiated in September 2000, should last one year and requires some $2 million in funding. The objectives of this phase will be to decrease the operating temperature of the HEVs, improve cold-start procedures, and begin manufacturing battery packs to be incorporated into the vehicle. We also wish to validate the new processes used to manufacture and assemble the battery parts and, in a bid to cut costs, test the new materials studied during Phase I.



Commercial impact of our R&D services

For over three years, LTEE has been the main supplier of R&D services for the firm Limtech, which is developing a process for manufacturing ultra-pure lithium carbonate, primarily for the electronics market. LTEE's work has enabled Limtech to develop a simple and innovative process which has honed its competitive edge. These critical steps were all successfully completed and the project is currently moving in a commercial direction with the construction of a $10-million plant in Shawinigan industrial park. With this first major industrial achievement, the structuring effect of LTEE's activities on the Mauricie region's regional development is well proven, which is all to Hydro-Québec's benefit. The revenues related to this outside activity total $5-million over three years.

The DROSCAR technology for the recovery of aluminum dross is also paying off. Two commercial installations have been set up in France at Soyer Affinage S.A. through the intermediary of the Chicoutimi-based engineering firm STAS (which signed a licensing agreement) and in South Africa for the firm AMP. Hydro-Québec will receive licensing revenues for the two installations, which have a combined installed capacity of close to 2 MW.

In terms of vitrification, our ongoing efforts have also highlighted LTEE's expertise. Our technology, which is based on the use of plasmas, helps make contaminated soil inert or stabilizes loose soil for construction purposes. In conjunction with the *direction principale Valorisation et participations*, LTEE has come up with two options: vitrification using an external reactor, a technology for which Hydro-Québec owns the intellectual property, and the direct-soil approach, which was developed in conjunction with Dr. Lou Circeo of the Georgia Institute of Technology in Atlanta. Currently, interest for these processes, which substantially reduce the amount of treated soil, is centered in Asia, due to the limited storage space and the loose soil found there. Three memoranda of agreement aimed at funding a joint development were signed this last year.

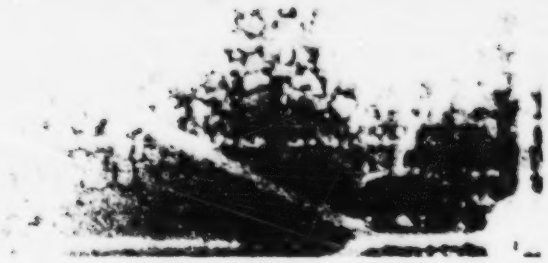
Construction of a first plant in Shawinigan

Unique grinder for nanocristalline powder

Our advanced materials researchers have unique expertise in developing and characterizing new materials in the energy sector. Our researchers, who are studying metal powders and metastable alloys, are focusing on nanocristalline materials produced by intense mechanical grinding. These materials have a very wide range of applications, from high-efficiency catalyzers to materials with improved properties, to nanocristalline hydrides used to store hydrogen.

In an effort to find more efficient ways of manufacturing and producing these nanocristalline powders, we acquired two high-energy grinders with production capacities of 0.5 kg/test and 1.5 kg/test, respectively. Backed by their expertise in this area, our researchers made major modifications to the devices' design and operating principles, and we now have a unique grinder capable of producing powders at a rate of 25 kg/test, or about 5 tonnes/year under normal operating conditions. We also developed devices for feeding raw materials and shrinking nanocristalline powders which produce new value-added materials safely and in a controlled environment.

Laboratories

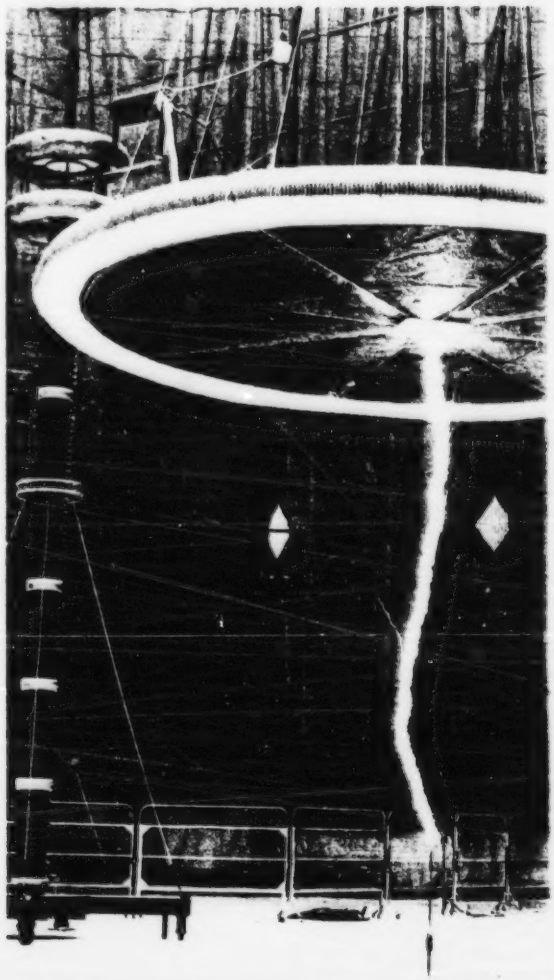


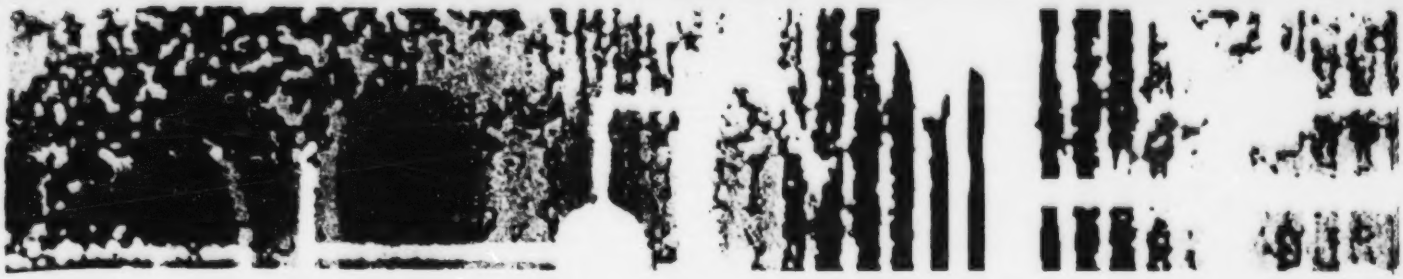
By innovating, Hydro-Québec has maintained its position as a leader in hydroelectric generation and the transmission of high-voltage electrical power. In addition to support in research and development, the utility has been able to rely on unique expertise and test installations.

Once again this year, our laboratories have made an exceptional contribution. For TransÉnergie and the Distribution Group in particular, they have conducted test programs on disconnect switches, grounding ties, windings, power transformers, etc. In 1999, work also continued on improving equipment performance and reliability. New test circuits now allow synthetic short-circuit making tests to be performed on high-voltage switchgear.

Furthermore, the utility once again enlisted our expertise to implement its research and test program on power system operation under conditions of ice. Power system simulation was also used, in one case for a test program carried out using the Hypersim all-digital simulator for generic models of a series and parallel static compensator. The results will be used to determine the most suitable mitigation equipment for Hydro-Québec's distribution system.

Several field measurement campaigns were conducted on behalf of the utility and for manufacturers. One such campaign demonstrated that one of an adjacent line's phases can be used to ensure uninterrupted service when a failure occurs on a distribution line. Finally, over 150 of the utility's business units called on our metrological expertise for the calibration of their measuring equipment.





High-voltage laboratory

We successfully completed various tests on transmission and distribution system equipment for our two internal clients, TransÉnergie and the Distribution Group. A wide range of equipment was tested, including 145-kV disconnect switches, grounding ties, 330-kV bushings, power transformers, shunt reactors, insulated grounding systems, capacitors, 25-kV switching cabinets, and even work gloves. The purpose was to verify the devices' condition and reliability, or validate their behaviour and performance to ensure that they still meet the utility's requirements.

Agreement renewed for five years

Work continued on the test program on the lightning laser-triggering method, launched in 1997, which consists in triggering lightning by laser and diverting it from its trajectory. We were thus able to reproduce the electrical phenomenon observed during storms and define the ideal conditions for triggering and capturing lightning before it strikes. Breakdown voltage tests were conducted on superimposed electrodes spaced about 10 m apart. The program is being carried out jointly with IREQ's lines department and the *Institut national de la recherche scientifique (INRS) Énergie et Matériaux*.

As part of the agreement with ABB, which was renewed for five more years and involves laboratory testing of equipment manufactured in ABB's Varennes plant, we conducted type and routine tests on 46 devices, transformers, and shunt reactors.

We also implemented major test programs on current transformers, connectors, insulators, capacitors, lightning arresters and insulated grounding systems for outside clients such as RITZ, Alsthom, Posi-Plus, AMP, GE, Dalian insulators, Dielve, Électro-Composites and Magatran.

Moreover, on the international scene, our laboratory was selected to take part in an inter-laboratory comparison program involving measuring systems. Overseen by the Helsinki University of Technology in Finland, the program is part of a two-year study on the traceability and mutual recognition of high-voltage impulse measurements. At the request of a CIGRÉ working group, 24 organizations from Europe, North and South America, and Pacific Asia are taking part in the study. Our laboratory proved equal to the task and successfully conducted comparative measurements of our own devices and those provided by Helsinki University.

The main objectives of the inter-laboratory campaign were to continue improving HT measurements and comparative measurement techniques, as well as to upgrade more difficult measurements such as full and chopped front impulse measurements with superimposed noise, oscillations and overshoot. Another objective was to develop and implement an AC/DC conversion which would be unanimously accepted for high-voltage testing, as well as establish the scientific basis necessary for reciprocal acceptance of HV impulse measurements. Lastly, the comparison program involved adopting a reciprocal recognition and acceptance method for reference and certification measurement systems. To meet these objectives, the test program included measurements ranging from 1 to 400 kV, carried out concurrently using equipment supplied by each laboratory as well as reference equipment provided by the Helsinki University of Technology, and sent to each of the participating organizations in turn.

High-power laboratory

For several years now, the high-power laboratory has been putting considerable effort into improving the performance and reliability of its equipment so that it can offer testing services of the highest quality which are both flexible and fast. In 1999, we made a number of improvements to the telecommand system and put it into service. These improvements consisted of new computers and fiber-optic links, as well as a special programmable card which serves as the communications interface with the laboratory's satellite stations. The work was done in conjunction with Hydro-Québec's transmission system computer specialists. Finally, this past year, we upgraded the satellite stations.

Meeting the requirements of international standards

Moreover, the refurbishing of four 1200-MVA short-circuit transformers will continue until 2000: the aim is to optimize the busbars, repair and change the bushings, and improve the transformer insulation.

In order to meet the requirements of the most recent draft amendments to international standards, we also installed new test circuits, notably for synthetic short-circuit making tests of up to 424 kV, 63 kA, for high-voltage switchgear (e.g. circuit breakers, disconnect switches, etc.). The development of these circuits was made possible thanks to the new controlled spark gap designed by a team of IREQ researchers. Under the new international standards, short-circuit making tests on high-voltage circuit breakers must be done at the nominal voltage, regardless of the breaker's pre-arcing time, which is what the installation allows. The first synthetic fault closing tests on circuit breakers were also conducted using the new controlled spark gap. The device is equipped with new components which produce transient voltages complying with international standards. The tests were carried out for various Hydro-Québec departments and outside clients.

We also acquired capacitor banks, which we will use to carry out capacitive current tests on medium-voltage circuit breakers and capacitor switches, as well as to simulate three-phase capacitor banks up to 60 MVAR and test circuit breakers rated 15 to 48 kV. This equipment has already been used to carry out tests for various manufacturers.

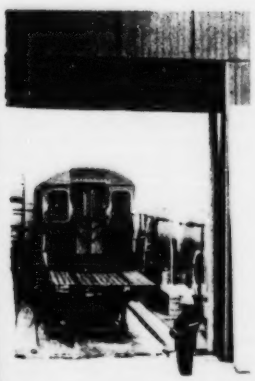
We also conducted a major test program to determine the origin of failures detected on lightning arresters at Hydro-Québec's Montagnais substation. A lightning arrester similar to those found at the substation was subjected to a series of tests. The next step is to test one of the in-service arresters.

We also validated a new de-icing method which consists in sending a short-circuit current through an ice-covered quad bundle some 55 m in length. Our test campaign, which was conducted on an outdoor test bench, is part of an R&D project carried out in conjunction with the mechanical and thermo-mechanical laboratory. We continue to run these tests throughout 2000 on a twin conductor bundle.

Other highlights this past year include tests on 15-kV, 600-A back-to-back capacitor banks and lightning surge tests conducted on behalf of various manufacturers. Lastly, our major test program involving line-charging tests on circuit breakers was very successful and involved capacitive current breaking tests to check the interval at which the laboratory can perform this type of test, including processing the results. These tests confirmed our laboratory's capabilities; using high-tech measuring and control systems, the tests (200 in all) were conducted at 90-second intervals. The top-rated laboratories carry out the same tests at 120- to 180-second intervals.

Mechanical and thermomechanical laboratory

IREQ's mechanical and thermomechanical laboratory has built and commissioned a new high-tech environmental test chamber, the only one of its kind in Canada and the laboratory's seventh such facility. The new test chamber and the associated data acquisition systems are rated among the top in the world. Because of its impressive size (6.7 m wide x 7.3 m high x 20.8 m long), the facility can be used to carry out tests on large-size equipment and parts, from electrical network apparatus to public-transit vehicles, at temperatures ranging from -50°C to 65°C. Mounted on an insulated floor, the chamber uses high-performance control tools which ensure uniform temperature and humidity during testing. It is also capable of simultaneously integrating electrical and mechanical tests over the entire range of environmental conditions.



Thanks to the new facility, we successfully completed a major campaign – a first for us – to test the heating, ventilating and air-conditioning (HVAC) systems in a subway car designed by the firm Bombardier Transportation, North America for the New York Transit Commission. The HVAC systems were tested in conditions similar to actual conditions. Highly accurate results were obtained for all the measurements: temperature, relative humidity, pressure differential, rpm of the systems' rotating parts, power, current, etc. The 250 sensors were scanned in less than one minute with the IREQ-designed Khaméléon measuring system for signal acquisition and processing. The expertise of IREQ's field-testing unit was put to use for the power measurements. The laboratory is now negotiating six new test programs for ground transport vehicles. Talks are also under way with various companies in the aircraft industry.

We also carried out a number of tests for our clients. These involved establishing diagnostics and solving technological problems related to the mechanical and thermomechanical behaviour of installations, as well as meeting the needs of equipment manufacturers. This year, our expertise was once again enlisted along with our laboratory's testing capabilities with respect to ice loading. The R&D programs that were conducted include the validation of a software program which calculates the time required to de-ice conductors using the Joule effect, based on varying accumulations of ice and climatic conditions. These tests were carried out on different types of conductors.

On the experimental line, we continued testing phase spacers on 120-kV lines at the request of the Lines department and TransÉnergie. These devices prevent contact between conductors, thus controlling the effects of galloping. We also carried out, on behalf of an Indian company, tests to validate the performance of spacer-dampers. Lastly, at the request of TransÉnergie, we tested, on a 200-m span, a de-icing method involving the projection of dry ice using specially insulated tools for live-line work.

We also made progress on our model of an underground system, used to simulate partial discharges. We completed the tests aimed at developing and characterizing a system for locating partial discharges. Other tests scheduled in 2000 will allow us to evaluate an initial prototype in a 25-kV duct and then in the field. Our accelerated aging tests aimed at predicting the residual life of in-service generator busbars are also progressing. The busbars were subjected to multiple electrical, thermal and mechanical stresses. The parameters of their condition could thus be determined using the *in-situ* partial-discharge method and diagnostic measurements.

Other work includes the test campaign aimed at verifying the reliability of insulator strings on Hydro-Québec's transmission system, carried out at the request of Hydro-Québec's civil-engineering works and materials department and TransÉnergie. These tests will continue through 2000. In addition, on behalf of manufacturers and Hydro-Québec departments, various temperature-rise tests were carried out on 315-kV and 735-kV disconnect switches, along with standardized and accelerated heat-cycle tests on electrical connectors. The utility's standardization department asked us to conduct aging tests to identify the main parameters characterizing the condition of power-system protection relays and to predict their residual service life. Lastly, at the request of the Distribution Group, we conducted, in conjunction with R&D teams and manufacturers, test campaigns on various types of system-reinforcing equipment, such as ties, anchors, crossarms, etc.

With respect to the submersible dry-type distribution transformer developed by the *Centre d'innovation sur le transport d'énergie du Québec* (CITEQ), we are continuing with the test program aimed at characterizing this technology. Cold-load startup and accelerated-cycle tests using diagnostic measurements were also carried out.

Other major work includes cycling tests on lithium-polymer batteries developed by Hydro-Québec and on conventional-type batteries, as well as vibration tests on M4V and HEV LPB battery prototypes assembled by ARGO-TECH. Our laboratory continues to make inroads into the optical ground wire market, and we carried out numerous test programs for various international manufacturers. We also conducted environmental-chamber tests to qualify several circuit breakers, as well as heat-cycle tests on low-voltage connectors on the underground distribution system and substation connectors. Lastly, at the request of the Montreal Urban Community Transit Corporation (MUCTC), our laboratory tested 126 metro guide bar insulators to assess their condition and level of reliability.

Bombardier Transportation du Nord-est New York

Power system simulation laboratory

Our laboratory carried out milestone studies on the behaviour of power systems and their equipment to meet the needs of Hydro-Québec and various manufacturers. At the request of the Distribution Group, we developed, validated and evaluated the performance of generic models of a series and parallel static compensator. The aim of the test program, which is part of a study initiated in 1998, is to assess the performance of mitigation equipment designed to attenuate various power system disturbances. In 2000, the project team intends to evaluate, in a test area containing the Hypersim all-digital simulator, distribution-system components, industrial load models, and actual direct-current motor drives, the performance of parallel (C.S.P. or Statcom) or serial (C.S.S. or DVR) commercial static compensators to better understand how they operate. The findings will be used to determine the most appropriate type of mitigation equipment for the distribution system.

Mitigating system disturbances

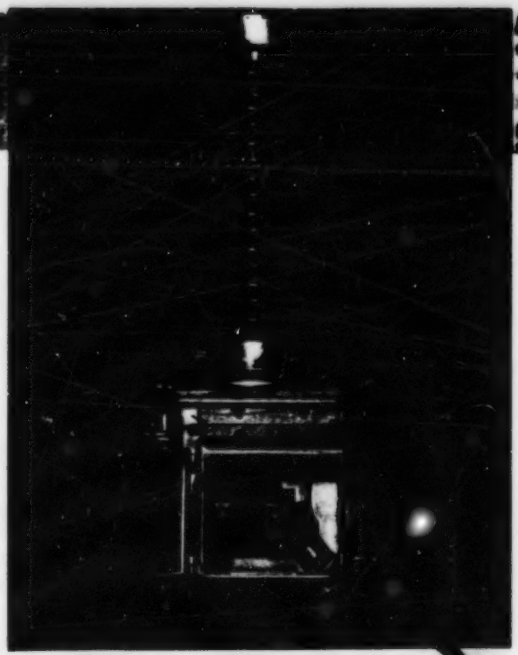
At the Outaouais converter station, Hydro-Québec's TransÉnergie division and Ontario Hydro are conducting a joint study with a view to building a new direct-current interconnection. At TransÉnergie's request, we carried out a test campaign to assess the behaviour of two 625-MW converter bridges as well as that of interconnected systems under various operating conditions. The tests, which are still under way, mainly involve checking the tie limits for both exports and imports of electricity. We will also be assessing possible interactions between the two interconnected systems, defining the main ways of controlling the interconnection and establishing the converter recovery time following various faults.

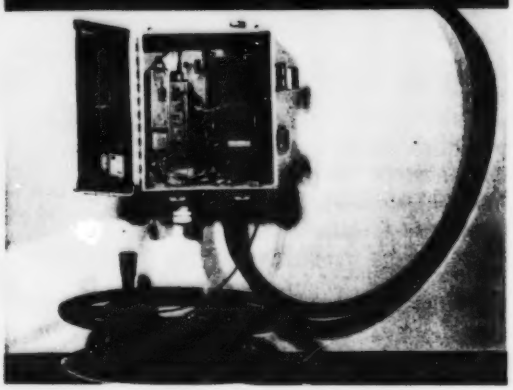
At the request of the firm Allied Signal Power Systems, we carried out a series of simulations of a 75-kVA micro-turbine which supplies a distribution system. The project involved evaluating the turbine's performance and assessing its interaction with the distribution system under different operating conditions. We checked the micro-turbine's control and protection systems and assessed the impact of harmonics induced by the MLI inverter. We also studied the operation of the control system, especially the measurement and synchronization units, during disturbances on the distribution system such as voltage imbalances, faults, frequency variations, and harmonics. The operation of the micro-turbine in autonomous mode was also studied. We plan to conduct other tests this year to optimize the control and protection systems.

At the request of *TransÉnergie Technologies*, the TransÉnergie subsidiary in charge of marketing the simulators, we worked on enhancing simulation tools by developing digital models of the hybrid simulator sold to Japan, adding new functionalities and implementing the international version of the Hypersim graphical interface. We also worked on optimizing *Power System Blockset*, designed at IREQ, which consists in a power system and control system simulation toolbox integrated with the Matlab-Simulink software program created by Mathworks.

In addition, in partnership with *TransÉnergie Technologies* and SGI, a major computer manufacturer, our engineers tested the use of a parallel commercial computer for real-time simulation. The partnership with SGI has many advantages, including a rapid increase in computer performance as well as complete after-sales service nationwide. This new generation of digital simulators, which we are currently using in our laboratory, is being marketed by *TransÉnergie Technologies*.

Lastly, our laboratory will be the first to receive ISO Guide 25 accreditation for the verification of the performance of in-service control systems and automatic controls and the evaluation of transient phenomena on the power system. Our laboratory also met the requirements of the Standards Council of Canada and the *Bureau des normes du Québec* during the audit and we expect to be accredited in June 2000.





Field-testing unit

This past year, our field-testing unit implemented test and measurement programs on behalf of various Hydro-Québec departments and industrial clients, in addition to collaborating on R&D projects. When line failures occur, one of an adjacent line's phases can be used to ensure uninterrupted service. We verified this technique at the request of the Distribution Group.

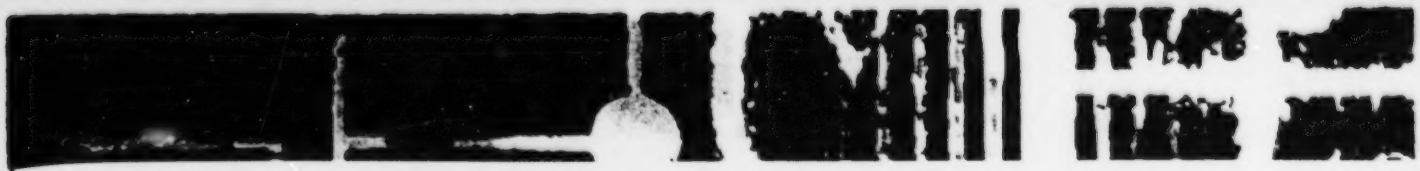
Using a brand-new test method, we carried out a series of measurements to ensure that the operation can be performed safely. We thus determined the contact voltage levels present when the distribution system is operated in this manner in order to ensure worker and public safety. Using a distribution transformer minimizes the test's impact on service continuity; furthermore, the new method can also be used to verify the safety of the installations in rural and urban networks.

We also collaborated on a study aimed at determining lightning-induced failure in distribution transformers. Using the miniaturized lightning surge generator, which we designed, we conducted diagnostic testing on equipment. The results provided us with additional data to help us identify the cause of the failures and propose ways of improving the transformers and reducing the failure rate.

In an effort to prevent failure of SF_6-insulated equipment, TransÉnergie asked us to study the condition of the equipment's insulation. The measurement campaign was also carried out using a partial-discharge detection method based on UHF narrowband on metal-clad SF_6-insulated switchgear at Viger substation.

For phenomena and disturbances which occur on Hydro-Québec's power system which are still not adequately understood and which affect power quality, we proceeded to validate measurement systems and software in order to extend their application to continuous monitoring and ensure that they can be controlled remotely. These systems can now be used for the acquisition of data, which are then transmitted to a workstation by network or phone for further analysis by our experts. We were able to detect the cause of the production shutdowns experienced by some industrial clients and found ways to solve the problems at the root of the shutdowns. These systems also enhanced the data of several projects carried out by IREQ researchers for TransÉnergie and Hydro-Québec's Distribution Group. They also help us assess power-system equipment in order to propose corrective measures and boost performance and reliability.

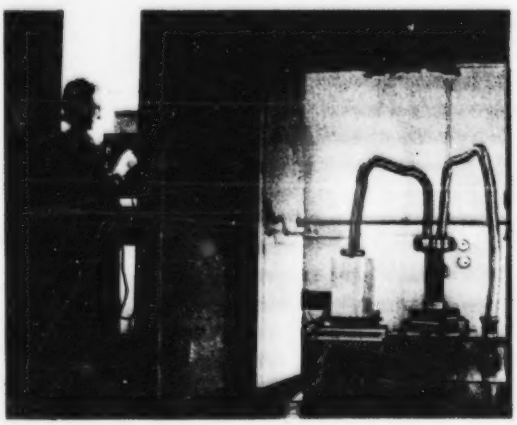
Conseil canadien des normes



Also on behalf of TransÉnergie, we supervised the development of a bandwidth adapter for capacitance voltage transducers and then verified it. The new device, which measures harmonics and transients from transformers installed in substations, supplements the range of equipment Hydro-Québec uses to assess power quality.

Moreover, the field-testing unit's expertise in measuring and analyzing electrical parameters was put to use by the mechanical and thermomechanical laboratory for tests on the air-conditioning, ventilation and heating systems of a subway car designed by Bombardier. Lastly, our experts worked with the *Institut de technologie supérieure* and the *École polytechnique de Montréal* on drafting an international paper on grounding systems, and contributed to international work on high-voltage direct-current links.

Ensuring worker and public safety



Calibration and repair laboratory

The past year saw a 19% increase in activity: we received 2,500 devices, including voltmeters, ammeters, wattmeters, voltage and current transformers, resistors, multi-purpose calibrators and high-precision multimeters. In fact, year after year our laboratory, which offers worldwide services of the highest metrological quality, sees an increase in the number of clients.

In addition to meeting the needs of the *direction principale Recherche et développement*, we provided services to over 150 of Hydro-Québec's units, as well as to about 40 companies in Québec, Ontario, B.C. and the United States.

Like the high-voltage laboratory, the calibration and repair laboratory was also successful in carrying out the required measurements, which specifically involved AC voltage measurement. Spanning one year, the study was conducted among 10 certified calibration laboratories located in Canada, the United States and Mexico. Out of the four Canadian laboratories selected, IREQ's calibration and repair laboratory was the only one based in Québec, with two others in Ontario and one in B.C. The interlaboratory campaign, conducted under the auspices of the North American Calibration Cooperation (NACC) and coordinated in Canada by the National Research Council of Canada (NRCC), aimed at ensuring reciprocal recognition of the validity of the calibration services offered in the three countries. NORAMET (The North American Cooperation in Metrology) also considers it a requirement for an international reciprocal recognition agreement. To this end, the investigative body delivered two pieces of equipment to the laboratory, each of which was subjected to 26 calibration parameters in the summer of 1999.

Lastly, after asking the NRC to extend the scope of its accreditation for AC and DC voltages to 120 kV and 100 kV respectively, and to reduce measurement uncertainties for low-voltage spans, the laboratory successfully passed the audit, fully meeting the requirements of the Calibration Laboratory Assessment Services (CLAS) program. We now hope to obtain a certificate during the first quarter of 2000, attesting to the fact that these parameters have been added.

NORAMET

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